

# Scoping Study for Monitoring Wetland Extent and Condition



This technical report has been previously published by the Queensland Government. The technical information in this publication is still current, however it may contain references to former departmental names. Please refer to the Department of Environment and Heritage Protection's website at [www.ehp.qld.gov.au](http://www.ehp.qld.gov.au) for up-to-date contact details.



Australian Government

Queensland  
Wetlands Program



Queensland  
Government



# Scoping Study for Monitoring Wetland Extent and Condition

## Author

Diane Conrick

This is the final report for the Scoping Study for Monitoring of Wetlands Extent and Condition project (WL NRM 04) of the Queensland Wetlands Programme, a joint initiative between the Australian and Queensland governments. The Queensland Wetlands Programme was established in 2003 to protect and conserve Queensland's wetlands.

## Acknowledgements

The author gratefully acknowledges the contributions to this report by Iris Haring (Project Officer), the members of the Project Team and the Steering Committee, the working group of the Department of Natural Resources and Water and the Environment Protection Agency officers that developed the Wetland Description Tool, and Kate Moore (University of Queensland) who illustrated the conceptual models. The participants of the workshop are also gratefully acknowledged, as are the workshop facilitators, Mary Maher (Mary Maher & Associates) and Emma Hawkins (Lloyd Consulting).

The Scoping Study for Monitoring of Wetlands Extent and Condition project team consisted of: Mike Ronan, Arthur Knight and Mark Cushing of the Environmental Protection Agency; Jon Marshall, Peter Negus and Christine White of the Department of Natural Resources and Water; Brian Stockwell of the Department of Primary Industries and Fisheries; Bruce Gray and Linda Collins of the Department of the Environment, Heritage, Water and the Arts; Donna Audas of the Great Barrier Marine Park Authority; and Kay Montgomery from SEQ Catchments.

The Scoping Study for Monitoring of Wetlands Extent and Condition project reference team consisted of: Peter Macdonald and Lynne Tuner of the Environmental Protection Agency; Paul Lawrence and Satish Choy of the Department of Natural Resources and Water; Veronica Blazely of the Department of the Environment, Heritage, Water and the Arts; and Donna Audas of the Great Barrier Reef Marine Park Authority.

### Disclaimer:

The views expressed and the conclusions reached in this publication are those of the authors and not necessarily those of the person consulted. The Queensland and Australian governments shall not be responsible in any way whatsoever to any person who relies in whole or part on the contents of this report.

This publication is copyright. However, the Queensland and Australian governments encourage wide dissemination of its contents and research, providing the governments are clearly acknowledged.

© The State of Queensland, Department of Natural Resources and Water 2007.

This report may be cited as: Scoping Study for Monitoring Wetland Extent and Condition, 2007.

978-0-9805174-1-5

## Contents

|                                                                    |           |
|--------------------------------------------------------------------|-----------|
| List of figures .....                                              | viii      |
| List of tables .....                                               | ix        |
| List of appendices.....                                            | xi        |
| Attachments .....                                                  | xi        |
| Abbreviations and Acronyms .....                                   | xii       |
| <b>Executive Summary .....</b>                                     | <b>xv</b> |
| <b>1 Introduction.....</b>                                         | <b>2</b>  |
| 1.1 Wetlands in Queensland .....                                   | 2         |
| 1.2 Wetland Indicators Scoping Study .....                         | 3         |
| 1.3 Project Objectives .....                                       | 4         |
| <b>2 Methods.....</b>                                              | <b>5</b>  |
| <b>3 Literature search .....</b>                                   | <b>6</b>  |
| 3.1 National resource condition indicators.....                    | 6         |
| 3.2 Current programs and indicators in Australia .....             | 6         |
| 3.3 Manuals and reviews .....                                      | 38        |
| <b>4 Wetland Classification.....</b>                               | <b>41</b> |
| 4.1 Wetland definition .....                                       | 41        |
| 4.2 Wetland types and sub-types .....                              | 41        |
| 4.3 Wetland Description Tool .....                                 | 43        |
| 4.4 Identification of Queensland wetland types.....                | 47        |
| <b>5 A Monitoring Framework .....</b>                              | <b>48</b> |
| 5.1 Indicator criteria.....                                        | 48        |
| 5.2 Indicator considerations .....                                 | 48        |
| 5.3 The framework .....                                            | 50        |
| 5.4 Conceptual Models .....                                        | 50        |
| <b>6 Application of the Framework in Queensland .....</b>          | <b>51</b> |
| 6.1 Stream and Estuarine Assessment Program .....                  | 51        |
| 6.2 Ecosystem Health Monitoring Program.....                       | 52        |
| 6.3 eWater .....                                                   | 53        |
| 6.4 Lake Eyre Basin .....                                          | 53        |
| 6.5 Sustainable Rivers Audit .....                                 | 53        |
| 6.6 Marine and Tropical Sciences Research Facility .....           | 54        |
| 6.7 Framework for the Assessment of River and Wetland Health ..... | 54        |

|                                                                                                    |            |
|----------------------------------------------------------------------------------------------------|------------|
| <b>7 Riverine Wetlands .....</b>                                                                   | <b>55</b>  |
| 7.1 Natural Resource Management Resource Condition Indicators.....                                 | 55         |
| 7.2 Stream and Estuarine Assessment Program .....                                                  | 55         |
| 7.3 Sustainable Rivers Audit .....                                                                 | 58         |
| 7.4 Lake Eyre Basin Rivers Assessment .....                                                        | 58         |
| 7.5 Marine and Tropical Sciences Research Facility .....                                           | 62         |
| 7.6 Ecosystem Health Monitoring Program.....                                                       | 62         |
| 7.7 Ambient Biological Monitoring and Assessment Program .....                                     | 65         |
| 7.8 Surface Water Ambient Network .....                                                            | 66         |
| 7.9 AquaBAMM .....                                                                                 | 66         |
| 7.10 Rapid Appraisal of Riparian Condition and Tropical Rapid Appraisal of Riparian Condition..... | 70         |
| <b>8 Estuarine and Marine Wetlands.....</b>                                                        | <b>72</b>  |
| 8.1 Natural Resource Management (NRM) Resource Condition Indicators .....                          | 72         |
| 8.2 Stream and Estuarine Assessment Program (SEAP) .....                                           | 75         |
| 8.3 EPA monitoring .....                                                                           | 80         |
| 8.4 Ecosystem Health Monitoring Program .....                                                      | 80         |
| 8.5 Marine and Tropical Sciences Research Facility .....                                           | 82         |
| 8.6 Coastal CRC.....                                                                               | 90         |
| 8.7 Seagrass Watch .....                                                                           | 94         |
| 8.8 AquaBAMM .....                                                                                 | 94         |
| <b>9 Lacustrine and Palustrine Wetlands.....</b>                                                   | <b>95</b>  |
| 9.1 Natural Resource Management (NRM) Resource Condition Indicators .....                          | 95         |
| 9.2 AquaBAMM .....                                                                                 | 101        |
| 9.3 CRCFE Dryland Refugia .....                                                                    | 105        |
| 9.4 Conceptual Models .....                                                                        | 107        |
| <b>10 Groundwater wetlands.....</b>                                                                | <b>146</b> |
| <b>11 Recommendations.....</b>                                                                     | <b>150</b> |
| <b>12 References .....</b>                                                                         | <b>151</b> |
| <b>Appendices .....</b>                                                                            | <b>156</b> |
| Appendix 1 Literature Search URLs .....                                                            | 156        |
| Appendix 2 Wetland classification systems.....                                                     | 158        |

|                                                                               |            |
|-------------------------------------------------------------------------------|------------|
| <b>Attachment A: Wetland Indicators Workshop Report.....</b>                  | <b>164</b> |
| <b>1 Executive Summary .....</b>                                              | <b>167</b> |
| <b>2 Introduction .....</b>                                                   | <b>168</b> |
| 2.1 Background information.....                                               | 168        |
| 2.2 The Wetland Indicators project.....                                       | 168        |
| 2.3 The workshop report .....                                                 | 168        |
| <b>3 Background to the Experts' Workshop.....</b>                             | <b>169</b> |
| <b>4 Building the Indicator Framework.....</b>                                | <b>170</b> |
| 4.1 Considerations for defining indicators .....                              | 170        |
| 4.1.1 Classification into wetlands types and sub-types.....                   | 170        |
| 4.1.2 Indicators 'fit for purpose' .....                                      | 170        |
| 4.1.3 Spatial scale .....                                                     | 171        |
| 4.1.4 Temporal scale.....                                                     | 171        |
| 4.1.5 Practicality: Skill level and cost requirements .....                   | 171        |
| 4.2 Wetland classification and building the indicators framework .....        | 172        |
| 4.3 Generic and specific indicators .....                                     | 172        |
| <b>5 The Indicator Framework.....</b>                                         | <b>173</b> |
| 5.1 Wetland indicator identification framework.....                           | 173        |
| 5.2 Wetland indicator considerations – a worked example.....                  | 174        |
| <b>6 Lacustrine Wetlands .....</b>                                            | <b>175</b> |
| 6.1 Lacustrine conceptual model .....                                         | 175        |
| 6.2 Lacustrine sub-type conceptual models.....                                | 179        |
| 6.2.1 Coastal dune lakes eg. Blue Lake, Stradbroke Island (window lake) ..... | 179        |
| 6.2.2 Terminal depression lakes.....                                          | 179        |
| 6.2.3 Depression lakes (inland, non-arid) .....                               | 180        |
| 6.2.4 Artificial lakese.g. Water supply dam .....                             | 181        |
| 6.2.5 Arid-zone saltwater river-fed lakes .....                               | 181        |
| 6.2.6 Inland salt lakes.....                                                  | 182        |
| <b>7 Palustrine Wetlands.....</b>                                             | <b>182</b> |
| 7.1 Palustrine conceptual models.....                                         | 182        |
| 7.2 Palustrine sub-type conceptual models.....                                | 186        |
| 7.2.1 Coastal forest swamps e.g. Melaleuca, Casuarina .....                   | 186        |
| 7.2.2 Coastal grass-sedge swampse.g. Bulkuru sedge.....                       | 187        |
| 7.2.4 Artificial (bore drains) .....                                          | 188        |
| 7.2.5 Natural groundwater springs.....                                        | 188        |
| 7.2.6 Herbs and forbs .....                                                   | 189        |
| 7.2.7 Freshwater meadows .....                                                | 189        |

|                                                                                                   |            |
|---------------------------------------------------------------------------------------------------|------------|
| <b>8 Groundwater .....</b>                                                                        | <b>190</b> |
| <b>9 Other Key Discussion Points.....</b>                                                         | <b>191</b> |
| 9.1 Characterising wetlands .....                                                                 | 191        |
| 9.1.1 Reference condition .....                                                                   | 191        |
| 9.1.2 Value judgements – setting environmental values for management .....                        | 191        |
| 9.2 Risk management approaches .....                                                              | 191        |
| 9.3 Remote methods or ground testing – when and why? .....                                        | 191        |
| 9.4 Extent of the wetlands .....                                                                  | 191        |
| 9.5 Users’ needs and capabilities .....                                                           | 192        |
| <b>10 Summary .....</b>                                                                           | <b>192</b> |
| <b>11 Way Forward .....</b>                                                                       | <b>193</b> |
| <b>Attachment List of Figures</b>                                                                 |            |
| Figure 1. Indicator specification. ....                                                           | 172        |
| Figure 2. Indicator framework. ....                                                               | 173        |
| Figure 3. Worked example of applying the matrix for a set indicator over a range of purposes..... | 174        |
| Figure 4. Lacustrine wetland (wet phase) conceptual model .....                                   | 177        |
| Figure 5. Lacustrine wetland (dry phase) conceptual model.....                                    | 178        |
| Figure 6. Palustrine wetland (wet phase) conceptual model .....                                   | 184        |
| Figure 7. Palustrine wetland (dry phase) conceptual model .....                                   | 185        |
| <b>Attachment List of Appendices</b>                                                              |            |
| Appendix A: Workshop Program – June 8 & 9, 2006 .....                                             | 194        |
| Appendix B: Participant List.....                                                                 | 195        |
| Appendix C: Presentations .....                                                                   | 197        |
| Appendix D: Workshop Groups .....                                                                 | 212        |
| Appendix E: Palustrine/Lacustrine Definitions.....                                                | 214        |
| Appendix F: Lacustrine Conceptual Models .....                                                    | 216        |
| Appendix F: Palustrine Conceptual Models .....                                                    | 222        |

## List of figures

|            |                                                                                                                                                                                                                   |     |
|------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|
| Figure 1.  | The Climate Classification of Australia map (Bureau of Meteorology).....                                                                                                                                          | 46  |
| Figure 2.  | A framework for selecting wetland indicators (Maher et al. 2006). ....                                                                                                                                            | 50  |
| Figure 3.  | Pressure-Stressor-Response (PSR) framework illustrating how human activities modify the prevailing biophysical conditions generated by natural drivers to elicit ecosystem responses (Marshall et al. 2006b)..... | 51  |
| Figure 4.  | EPA's Water Quality Management Framework.....                                                                                                                                                                     | 52  |
| Figure 5.  | Freshwater Biogeographic Provinces of Queensland. The provinces were identified by analysis of macroinvertebrate data and tested using fish data. ....                                                            | 65  |
| Figure 6.  | Relationship between the Australian Water Resources 2005 – Framework for the Assessment of River and Wetland Health project and the National Wetland Indicators project. ....                                     | 96  |
| Figure 7.  | Lacustrine wetland (wet phase) conceptual model.....                                                                                                                                                              | 112 |
| Figure 8.  | Lacustrine wetland (dry phase) conceptual model. ....                                                                                                                                                             | 113 |
| Figure 9.  | Coastal dune lake (lacustrine) conceptual model. ....                                                                                                                                                             | 115 |
| Figure 10. | Terminal depression lakes (lacustrine) conceptual model.....                                                                                                                                                      | 117 |
| Figure 11. | Inland non-arid lakes (lacustrine) conceptual model .....                                                                                                                                                         | 120 |
| Figure 12. | Artificial lakes (lacustrine) conceptual model.....                                                                                                                                                               | 122 |
| Figure 13. | Arid zone lakes (lacustrine) conceptual model.....                                                                                                                                                                | 124 |
| Figure 14. | Inland salt lakes (lacustrine) conceptual model.....                                                                                                                                                              | 127 |
| Figure 15. | Palustrine wetland (wet phase) conceptual model.....                                                                                                                                                              | 130 |
| Figure 16. | Palustrine wetland (dry phase) conceptual model.....                                                                                                                                                              | 131 |
| Figure 17. | Coastal forest swamp (palustrine) conceptual model .....                                                                                                                                                          | 134 |
| Figure 18. | Coastal grass-sedge swamp (palustrine) conceptual model.....                                                                                                                                                      | 136 |
| Figure 19. | Inland arid zone swamp (palustrine) conceptual model. ....                                                                                                                                                        | 139 |
| Figure 20. | Artificial swamps (bore drain) (palustrine) conceptual model.....                                                                                                                                                 | 141 |
| Figure 21. | Natural groundwater (palustrine) conceptual model. ....                                                                                                                                                           | 143 |
| Figure 22. | Freshwater meadow/herbs and forbs (palustrine) conceptual model.....                                                                                                                                              | 145 |
| Figure 23. | Characteristics of main aquifer types (McNeil & Clarke 2007). ....                                                                                                                                                | 146 |

## List of tables

|           |                                                                                                                                                         |    |
|-----------|---------------------------------------------------------------------------------------------------------------------------------------------------------|----|
| Table 1.  | National Resource Condition Matters for Target. ....                                                                                                    | 7  |
| Table 2.  | Recommended indicators for wetland Matters for Target. ....                                                                                             | 8  |
| Table 3.  | AusRivAS indicators. ....                                                                                                                               | 9  |
| Table 4.  | Themes and indicators currently in use and being developed for the Sustainable Rivers Audit. ....                                                       | 11 |
| Table 5.  | Sub-indices and variables identified for the 2004 benchmark Victorian Index of Stream Condition (DSE 2005a). ....                                       | 12 |
| Table 6.  | Sub-indices and measures for the Victorian Index of Wetland Condition (DSE 2005b). ....                                                                 | 13 |
| Table 7.  | Indicators proposed by Spencer et al. (1998) to monitor the condition of floodplain wetlands of the Murray-Darling Basin. ....                          | 14 |
| Table 8.  | Indices and measures used by the WetlandCare Wetland Assessment Technique ....                                                                          | 15 |
| Table 9.  | Indicators and measures used in the Queensland Freshwater Ecosystem Health Monitoring Program. ....                                                     | 16 |
| Table 10. | Variables measured in the Dryland Refugia project (Marshall et al. 2006a). ....                                                                         | 17 |
| Table 11. | RARC sub-indices and indicators. ....                                                                                                                   | 20 |
| Table 12. | TRARC sub-indices and indicators. ....                                                                                                                  | 21 |
| Table 13. | AquaBAMM criteria and indicators for riverine and non-riverine wetlands. ....                                                                           | 22 |
| Table 14. | Catchment, reach and geomorphic unit characteristics measured in the Geomorphic River Styles method. After Brierley et al. (1996). ....                 | 23 |
| Table 15. | ANZECC core environmental indicators, Commonwealth State of the Environment 2006, and Queensland State of the Environment 2003 wetland indicators. .... | 26 |
| Table 16. | Indicator headings and indicators identified for the floodplains and wetlands of the Murray-Darling Basin (Baldwin et al. 2005). ....                   | 39 |
| Table 17. | Wetland classification systems. ....                                                                                                                    | 42 |
| Table 18. | Wetland Description Tool layers to assist in classifying wetlands in Queensland. ....                                                                   | 44 |
| Table 19. | Criteria for selecting indicators. ....                                                                                                                 | 48 |
| Table 20. | Riverine NRM resource condition indicators. ....                                                                                                        | 55 |
| Table 21. | SEAP Indicators and measures identified for collection in the Central province of Queensland. ....                                                      | 57 |
| Table 22. | Themes, indicators and measures currently in use and being developed for the Sustainable Rivers Audit. ....                                             | 58 |

|           |                                                                                                                                                                                           |     |
|-----------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|
| Table 23. | Suggested themes, indicators and measures for detecting change in condition of different regions of Lake Eyre Basin. ....                                                                 | 60  |
| Table 24. | Biophysical indicators identified and tested against natural and disturbance gradients in the wet tropics for MTSRF. ....                                                                 | 63  |
| Table 25. | Ecosystem Health Monitoring Program freshwater indicators and measures. ....                                                                                                              | 64  |
| Table 26. | AquaBAMM criteria, indicators and measures for riverine wetlands. ....                                                                                                                    | 66  |
| Table 27. | RARC sub-indices and indicators. ....                                                                                                                                                     | 70  |
| Table 28. | TRARC sub-indices, indicators and measures. ....                                                                                                                                          | 71  |
| Table 29. | Current recommended indicators for Estuarine, Coastal and Marine Matter for Target. ....                                                                                                  | 72  |
| Table 30. | Proposed indicators for Estuarine, Coastal and Marine Matter for Target, and measures currently undergoing trials in Queensland (R. Thorman pers.comm.; Scheltinga & Moss in prep.a)..... | 74  |
| Table 31. | Proposed SEAP stressors (and direct pressures on the system) and indicators for each phase of the models (Scheltinga & Moss in prep.b). ....                                              | 76  |
| Table 32. | Water quality indicators and measures collected by the EPA in rivers, estuaries and coastal areas of eastern Queensland. ....                                                             | 80  |
| Table 33. | Indicators and measures used in the estuarine/marine component of the EHMP. ....                                                                                                          | 81  |
| Table 34. | Estuarine indicators proposed for investigation in the MTSRF project: Marine and estuarine indicators and thresholds of concern. ....                                                     | 82  |
| Table 35. | Potential water quality indicators for estuaries and inshore coral reefs of the Great Barrier Reef. ....                                                                                  | 83  |
| Table 36. | Potential indicators for determining coral reef health in the Great Barrier Reef (Sweatman 2007). ....                                                                                    | 84  |
| Table 37. | Key indicators identified by the Mesoamerican Indicator Framework for assessing the health of Central American reefs. ....                                                                | 86  |
| Table 38. | Proposed categories of tidal wetland change and indicators for assessing coastal and estuarine habitat (from Duke et al. 2003, Schaffelke et al. 2005). ....                              | 90  |
| Table 39. | Keys to assist identification of types of change in tidal wetland habitats (Duke et al. 2003). ....                                                                                       | 92  |
| Table 40. | Measures collected by community groups in Seagrass-Watch (McKenzie et al. 2003). ....                                                                                                     | 94  |
| Table 41. | Current recommended indicators for wetland (lacustrine and palustrine) Matter for Target. ....                                                                                            | 95  |
| Table 42. | Proposed wetland NRM resource condition indicators. ....                                                                                                                                  | 97  |
| Table 43. | Proposed AquaBAMM criteria, indicators and measures for freshwater non-riverine wetlands. ....                                                                                            | 101 |
| Table 44. | Physical variables measured in the Dryland Refugia project (Marshall et al. 2006a). ....                                                                                                  | 105 |
| Table 45. | Lacustrine wetlands conceptual model. ....                                                                                                                                                | 107 |

|                                                                                 |     |
|---------------------------------------------------------------------------------|-----|
| Table 46. Conceptual model for coastal dune lakes. ....                         | 114 |
| Table 47. Conceptual model for terminal depression lakes.....                   | 116 |
| Table 48. Conceptual model for depression lakes (inland, non-arid). ....        | 118 |
| Table 49. Conceptual model for artificial lakes. ....                           | 121 |
| Table 50. Conceptual model for arid-zone saltwater river-fed lakes.....         | 123 |
| Table 51. Conceptual model for inland salt lakes. ....                          | 125 |
| Table 52. Palustrine wetlands conceptual model. ....                            | 128 |
| Table 53. Conceptual model for coastal forest swamps. ....                      | 132 |
| Table 54. Conceptual model for coastal grass-sedge swamps. ....                 | 135 |
| Table 55. Conceptual model for inland arid-zone swamps. ....                    | 137 |
| Table 56. Conceptual model for artificial swamps (bore drains).....             | 140 |
| Table 57. Conceptual model for natural groundwater springs.....                 | 142 |
| Table 58. Conceptual model for freshwater meadows/herbs and forbs. ....         | 144 |
| Table 59. Water quality indicators for aquifer type (McNeil & Clarke 2007)..... | 147 |
| Table 60. Conceptual model for underground wetlands. ....                       | 148 |

## List of appendices

|                                                        |     |
|--------------------------------------------------------|-----|
| Appendix 1 Literature Search URLs.....                 | 156 |
| Appendix 2 Wetland classification systems.....         | 158 |
| 1. Ramsar Classification System for Wetland Type ..... | 158 |
| 2. A Directory of Important Wetlands in Australia..... | 162 |

## Attachments

|                                                       |     |
|-------------------------------------------------------|-----|
| Attachment A: Wetland Indicators Workshop Report..... | 164 |
|-------------------------------------------------------|-----|

## Abbreviations and Acronyms

|          |                                                                        |
|----------|------------------------------------------------------------------------|
| ABMAP    | Ambient Biological Monitoring and Assessment Program                   |
| AchE     | Acetyl Cholinesterase                                                  |
| AIMS     | Australian Institute of Marine Science                                 |
| ANZECC   | Australian and New Zealand Environment and Conservation Council        |
| APFD     | Annual Proportion of Flow Deviation                                    |
| AquaBAMM | Aquatic Biodiversity Assessment and Mapping Method                     |
| ARI      | Annual Return Interval                                                 |
| ASFB     | Australian Society for Fish Biology                                    |
| ASRIS    | Australian Soil Resource Information System                            |
| AusRivAS | Australian River Assessment System                                     |
| AUSWAMP  | Australian Wetlands Assessment and Monitoring Program                  |
| AWR      | Australian Water Resources                                             |
| BOD5     | Biological Oxygen Demand over 5 days                                   |
| CAMBA    | China-Australia Migratory Bird Agreement                               |
| CBD      | Convention on Biological Diversity                                     |
| CFEV     | Conservation of Freshwater Ecosystem Values                            |
| CMA      | Catchment Management Authorities                                       |
| COP9     | 9th Conference of the Parties of the Ramsar Convention                 |
| COTS     | Crown of Thorns Starfish                                               |
| CRC      | Cooperative Research Centre                                            |
| CRCFE    | Cooperative Research Centre for Freshwater Ecology                     |
| DIWA     | Directory of Important Wetlands of Australia                           |
| DOC      | Dissolved Organic C                                                    |
| DON      | Dissolved Organic N                                                    |
| DPI&F    | Department of Primary Industries and Fisheries                         |
| DSE      | Victorian Department of Sustainability and Environment                 |
| EAASSN   | East Asian-Australasian Shorebird Site Network                         |
| EC       | Electrical Conductivity                                                |
| ECM      | Estuarine, Coastal and Marine                                          |
| EHMP     | Ecosystem Health Monitoring Program                                    |
| EPA      | Environmental Protection Agency                                        |
| EPBCAct  | Environment Protection and Biodiversity Conservation Act 1999          |
| EPT      | Ephemeroptera (mayfly), Plecoptera (stonefly), Trichoptera (caddisfly) |
| EROD     | Ethoxyresorufin O-deethylase                                           |
| EVs      | Environmental Values                                                   |
| FARWH    | Framework for the Assessment of River and Wetland Health               |

|        |                                                                        |
|--------|------------------------------------------------------------------------|
| FMS    | Farm Management System                                                 |
| FORAM  | Foraminifera Index                                                     |
| GAB    | Great Artesian Basin                                                   |
| GAR    | Geomorphic Assessment Rivers                                           |
| GBR    | Great Barrier Reef                                                     |
| GBRMPA | Great Barrier Reef Marine Park Authority                               |
| GDE    | Groundwater Dependent Ecosystems                                       |
| GPP    | Gross Primary Production                                               |
| HAT    | High Astronomical Tide                                                 |
| HGM    | Hydrogeomorphic method                                                 |
| ICAG   | Intergovernmental Coastal Advisory Group                               |
| IPAM   | Imaging PAM = Imaging Pulse Amplitude Modulated fluorometry            |
| ISC    | Index of Stream Condition                                              |
| IWC    | Index of Wetland Condition                                             |
| JAMBA  | Japan-Australia Migratory Bird Agreement                               |
| LAT    | Low Astronomical Tide                                                  |
| LEB    | Lake Eyre Basin                                                        |
| M&E    | Monitoring and Evaluation                                              |
| MAR    | Meso American Reef Program                                             |
| MDBC   | Murray Darling Basin Commission                                        |
| MEA    | Millennium Ecosystem Assessment                                        |
| MEWG   | Monitoring and Evaluation Working Group                                |
| MFT    | Matter for Target                                                      |
| MHWS   | Mean High Water Springs                                                |
| MTSRF  | Marine and Tropical Sciences Research Facility                         |
| N      | Nitrogen                                                               |
| NAP    | National Action Plan for Salinity and Water Quality                    |
| NCAct  | Nature Conservation Act (Qld)                                          |
| NGO    | Non-government Organisation                                            |
| NLWRA  | National Land and Water Resources Audit                                |
| NM&EF  | National Natural Resource Management Monitoring & Evaluation Framework |
| NRHP   | National River Health Program                                          |
| NRM    | Natural Resource Management                                            |
| NRW    | Natural Resources and Water (Queensland State Agency)                  |
| NWC    | National Water Commission                                              |
| NWI    | National Water Initiative                                              |
| P      | Phosphorus                                                             |
| PAM    | Pulse Amplitude Modulated fluorometry                                  |

|         |                                                                  |
|---------|------------------------------------------------------------------|
| PVR     | Pressure-Vector-Response Model                                   |
| QWJGT   | Queensland Wetlands Joint Government Taskforce                   |
| QWP     | Queensland Wetlands Programme                                    |
| R       | Respiration                                                      |
| RARC    | Rapid Appraisal of Riparian Condition                            |
| RE      | Regional ecosystems                                              |
| RE      | Regional Ecosystems                                              |
| RivPACS | River Invertebrate Prediction and Classification System          |
| SAR     | Sodium Adsorption Ratio                                          |
| SEAP    | Stream and Estuarine Assessment Program                          |
| SIGNAL  | Stream Invertebrate Grade Number – Average Level                 |
| SLATS   | Statewide Landcover and Trees Study (NRW database)               |
| SoE     | State of the Environment Reporting                               |
| SOR     | State of the Rivers                                              |
| SRA     | Sustainable Rivers Audit                                         |
| STP     | Sewage Treatment Plant                                           |
| SWAMPS  | Swan Wetlands Aquatic Macroinvertebrate Pollution Score          |
| TDS     | Total Dissolved Salts                                            |
| TRARC   | Tropical Rapid Appraisal of Riparian Condition                   |
| TUMRA   | Traditional Use of Marine Resources Agreement                    |
| UNESCO  | United Nations Educational, Scientific and Cultural Organization |
| USEPA   | United States Environmental Protection Agency                    |
| WQ      | Water Quality                                                    |
| WQO     | Water Quality Objectives                                         |
| WWF     | World Wildlife Fund                                              |

# Executive Summary

## Executive Summary

Wetlands are an important part of the natural landscape, providing provisional (food and water), regulatory (flood mitigation, safeguard against droughts), supporting (soil formation, nutrient cycling), and cultural (recreational, spiritual) services. In recent years, the design of wetland monitoring programs has become more robust with a greater emphasis on the purpose of the program and an understanding of the functions, drivers, processes and pressures operating in the wetland.

Rivers and marine-estuarine systems have been monitored and assessed in Queensland for many years but lacustrine and palustrine systems are not currently monitored under any broad, consistent program. NRM regional bodies are beginning to target wetlands within the scope of management action targets and resource condition targets, but they require direction and support to do so. Research bodies (universities, state agencies, industry) target specific systems or regions and ask precise questions, but do not generally address condition and trend issues that would be asked by State agencies and NRM groups.

## The Queensland Wetlands Programme

The Queensland Wetlands Programme was set up *'to support projects and programs that will result in long term benefits to the sustainable use, management, conservation and protection of the Queensland wetlands'*. It supports priority projects for development of tools that assist in the management of wetlands, and regional delivery projects that utilise the tools developed.

Queensland has the widest range of wetland types in Australia, as identified by the *Directory of Important Wetlands of Australia* (DIWA) (Environment Australia 2001), many of which are not found in other parts of Australia. Several broad wetland categories are recognised under the Programme (marine, estuarine, riverine, palustrine, lacustrine, artificial and subterranean), all of which are consistent with the classifications used by Ramsar, DIWA, and the recently proposed Australian Wetlands Inventory.

## The Wetland Indicators Scoping Study

This project's aim is to review and develop indicators for assessing extent, distribution and condition of wetlands. The identification of indicators will inform both the Wetlands Inventory project, which forms the basis of the wider Wetlands Information System for the storage, maintenance, updating and delivery of wetlands information to multiple stakeholders, and the baseline resource condition assessment which was recommended by the Programme's MER Strategy.

Major outputs of this project include an 'expert' workshop to 'determine appropriate indicators and methodologies', a literature review of indicators of condition, methods used, and programs using these indicators, a wetland classification system for Queensland, and conceptual models for Queensland wetlands.

# Executive summary

## Wetland Classification

In order to report on the extent and distribution of wetlands, it is necessary to have an appreciation of wetland types. There are many wetland classification systems in use throughout Australia, all of which will need to translate to the DIWA wetland types in order to report nationally. This project proposed a Wetland Description Tool to assist in this process. The Tool has attributes which address characteristics of wetlands at increasingly smaller scales (continental, ecosystem, landscape, and local). Each category has specific layers to identify different features of wetlands that have traditionally been used in classification systems e.g. geographic location, climate, water sources, and dominant vegetation. Each layer identifies attributes that can be sourced using techniques such as remote sensing and data trawling. The layers and their attributes were selected so that when other classification systems are translated, there is an appropriate category to match the wetland type. A latter phase of this project has been to use and test the Wetland Description Tool using wetland types identified through the literature

## Monitoring Framework

The workshop outcomes included a Monitoring Framework which considers indicator criteria, purpose of the program, temporal and spatial scales, skill levels required, and economic feasibility. Identification of wetland descriptors and subsequent subtypes direct the development of conceptual models and identification of key features of the wetland including drivers, pressures, and impacts that are important to the functioning of the wetland. Wetland sub-types that emerged through the workshop process were a mixture of palustrine and lacustrine wetlands identified by geographic location, vegetation, and geomorphology. Discussions following the workshop determined that the principles of the monitoring framework are evident in other wetland programs in Queensland.

## Current programs in Queensland

Current programs in Queensland wetlands are investigated in detail with indicators and measures provided. Riverine programs include the NRM resource condition indicators, the Stream and Estuarine Assessment Program, the Sustainable Rivers Audit, the Lake Eyre Basin Rivers Assessment, the Marine and Tropical Sciences Research Facility Program, the Freshwater Ecosystem Health Monitoring Program, the Ambient Biological Monitoring and Assessment Program, the Surface Water Ambient Network, AquaBAMM (Aquatic Biodiversity Assessment and Mapping Method), the Rapid Appraisal of Riparian Condition (RARC), and the Tropical Rapid Appraisal of Riparian Condition (TRARC).

Estuarine and marine programs include the NRM resource condition indicators, the Stream and Estuarine Assessment Program, EPA monitoring, the Ecosystem Health Monitoring Program, the Marine and Tropical Sciences Research Facility Program, the Coastal CRC products, the Seagrass-Watch program, and AquaBAMM.

Lacustrine and palustrine wetlands programs include the NRM resource condition indicators and the proposed indicators determined by the National Matters for Target wetland indicators review, AquaBAMM, the CRCFE Dryland Refugia project, and the conceptual models developed at the workshop.

Groundwater programs in Queensland were discussed and a conceptual model developed at the workshop presented.

## Recommendations

One of the major outcomes of this project was to be a set of recommendations to inform the national review of the Matters for Target wetland indicators. As the national project is nearing completion at the same time as this project, that outcome has become somewhat obsolete. In its stead, the knowledge and information that has been gained from this project has been used to inform the national indicators project, including:

- The literature search was modified for use in the national workshop background report and incorporated into the final report, and
- The wetland classification work provided the basis for the 'Wetland Description Tool' which was delivered to the jurisdictional workshops for comment and modification.

The conceptual models that were developed in the Wetland Indicators workshop were selected intuitively, rather than by any methodical selection process. Part of the reason for this was the absence of any agreed classification system for wetlands in Queensland. Both the National Wetland Indicators project and this project see a need to develop conceptual models for all wetland types. As different pressures and stressors operate in different wetland types, this will provide a basis for understanding different wetlands and, therefore, the selection of appropriate indicators for monitoring condition. Models have been developed using pressure, stressor, response models for estuarine systems (OzEstuaries and SEAP) and are under development for bioprovincial riverine systems in Queensland (SEAP). This project recommends that the lacustrine and palustrine conceptual models be reviewed and redeveloped using the recommended classification system.

In developing the monitoring framework, one of the many points stressed was that alternative methods should be developed for application to all skill levels. This would then engage all stakeholders from community level, with relatively limited capabilities in more complex indicators, researchers, and all levels of government. This may be possible for some indicators, but it quickly became apparent that, for other indicators, this will not be possible. There are indicators that community groups or NRM regional bodies will not have the fiscal or physical resources

to monitor e.g. remote sensing for both extent and distribution, and condition. And there are some indicators that require products such as remote sensing layers that are beyond the scope of State agency purchasing power, but may be available at a national level. This project recommends that all levels of government, researchers and regional/community groups liaise closely to enhance wetland extent, distribution and condition monitoring e.g. common remote sensing layers be provided to State agencies for mapping and condition monitoring which is provided to NRM regional bodies for use in their regions; relevant State agency monitoring information be provided to NRM bodies.

This report has presented detailed information on indicators that are in use or are proposed for assessment or monitoring. It has become apparent that the selection of indicators needs to be a purpose driven exercise, and to prescribe a set of indicators in this document for monitoring could invite failure in the program to deliver accurate assessments. It is recommended that the information provided here be a starting point for selecting indicators, that conceptual models of the system under investigation be developed, and appropriate indicators be selected on the basis of purpose, scale, cost, and skill.



# 1. Introduction

Wetlands have been closely aligned with the success of human civilisations, providing food and water resources, ecosystem services and aesthetic values. Human activities in the past two centuries encroached on wetlands, turning them into agricultural land, using them as waste depositories, and stripping them of their natural resources (Mitsch & Gosselink 2000; MEA 2005). In recent years, the value of wetlands as an integral part of the landscape needing protection and management has been recognised, prompting governments to reassess how they are managed to maintain these vital functions.

Successful wetland management relies upon knowledge of the ecological value of wetlands, and good monitoring and assessment, which in turn is based upon a firm understanding of the functions, drivers, processes and pressures operating in the wetland, catchment and region (Finlayson et al. 2005). Aquatic scientists have worked hard to develop management methods that are widely applicable yet sensitive to human impacts. Part of this process has been to identify indicators of health or condition that are appropriate for the purpose of the study and reflect what is happening in the wetland. They must be transparent, testable and scientifically sound and have the ability to adequately reflect the complexity of a system in management terms (UNESCO 2003).

In recent years, the way in which wetland monitoring and assessment is approached has developed to the point of designing robust programs that consider the ecological value of wetlands in conjunction with relevant drivers, pressures, and stressors. In conjunction with this improved approach to identifying appropriate indicators, the wetland monitoring community has expanded from being the enclave of research scientists to include NRM agencies and community groups. With this came the need to provide direction for non-specialists in selecting appropriate indicators and methods to monitor wetlands.

## 1.1 Wetlands in Queensland

Wetland monitoring in Queensland has been, to date, confined within systems. Rivers and marine-estuarine systems have been monitored and assessed for many years at both broad and specific scales by State and Local Government agencies, science bodies (universities, CSIRO, etc), regional bodies, and community groups. Lacustrine and palustrine systems are not currently monitored under any broad, consistent program. There are no State-sponsored state-wide monitoring programs for lacustrine and palustrine wetlands. NRM regional bodies are beginning to target wetlands within the scope of management action targets and resource condition targets, but they require a robust framework to do so. Research bodies (universities, state agencies, industry) target specific systems or regions and ask specific questions, but do not generally address condition and trend questions.

The Bilateral Agreement between the Australian Government and the State of Queensland, signed in 2004, prompted the establishment of the Queensland Wetlands Programme the goal of which is *'to support projects and programs that will result in long term benefits to the sustainable use, management, conservation and protection of the Queensland wetlands'*. The Programme administers two sub-programmes: the Great Barrier Reef Coastal Wetlands Protection Plan, to develop and implement measures for the long-term conservation and management of wetlands in the Great Barrier Reef catchment as per the strategies in the 'Reef Water Quality Protection Plan', and the Natural Heritage Trust Wetlands Programme, to develop and implement measures to support Queensland in the conservation and management of wetlands as outlined in the Bilateral Agreement. The first major deliverable from the Programme is priority projects to assist in the management of wetlands e.g. mapping and inventory, management profiles, and information review and gap analysis, and the second is to further the prospects for wetland conservation and management through regional delivery projects utilising the tools developed under the first deliverable (Conrick 2005).

This project is one of a suite of projects under the Programme that is developing tools which will enable wetlands to be managed well in Queensland. This

project's aim is to review and develop indicators for assessing extent, distribution and condition of wetlands. Without appropriate extent and resource condition indicators, and baseline information on wetlands in Queensland, it will be difficult to establish whether the goal is being achieved.

For any meaningful monitoring framework it is important to understand the scope and specifics of wetlands in Queensland. Queensland has the widest range of wetland types in Australia, as identified by the *Directory of Important Wetlands of Australia* (DIWA) (Environment Australia 2001), many of which are not found in other parts of Australia. Several broad wetland categories are recognised under the Programme (marine, estuarine, riverine, palustrine, lacustrine, artificial and subterranean), all of which are consistent with the classifications used by Ramsar, DIWA, and the recently proposed Australian Wetlands Inventory.

Under the National Natural Resource Management (NRM) Monitoring and Evaluation Framework (NM&EF), the Matters for Target list the indicator headings and indicators for reporting by NRM Bodies throughout Australia; they are also linked to both state and national State of the Environment reporting. Wetlands are addressed under two Matters for Target (Inland aquatic ecosystems integrity and Estuarine, coastal and marine habitats integrity), both of which are currently undergoing review. In Queensland, the indicators have yet to be fully tested at a scale that supports resource planning and assessment. In addition, there is general acceptance that the indicators for wetland extent and condition are in need of revision (NLWRA 2005). This anomaly is being addressed by both this project, the Wetland Indicators Scoping Study, and by the national review of wetland indicators (lacustrine and palustrine) (Conrick et al. 2007).

## 1.2 Wetland Indicators Scoping Study

Under Clause 24 of the Bilateral Agreement i.e. to develop and implement new statutory planning and development assessment arrangements to protect wetlands, the Queensland Wetlands Programme is funding the development of several tools to assist in the successful management, conservation and restoration of Queensland wetlands.

One of these projects, the Wetlands Inventory Database, is being developed to provide a data storage mechanism for wetlands information. It forms the basis of the wider Wetlands Information System for the storage, maintenance, updating and delivery of wetlands information to multiple stakeholders. It will rely upon appropriate wetland indicators being established so that inventory fields can be identified which will allow the database to act as an appropriate mechanism for data capture and storage of monitoring information.

A recommendation from the Queensland Wetlands Programme Monitoring, Evaluation and Reporting Strategy (Conrick 2005) was to establish a baseline resource condition for Queensland wetlands by the end of the Programme (2008). In order to do this task, appropriate indicators needed to be identified, tested and agreed upon. The identification of indicators to inform both the Wetlands Inventory project and the baseline resource condition is one of the tasks of the Wetland Indicators Scoping Study.

Monitoring and Evaluation trials in Queensland funded by the NLWRA identified that wetland indicators were not considered by regional bodies when developing their Plans, as they were seen to be 'impractical and resource intensive', there were no national standards for monitoring, and the current NM&EF wetland indicators were based on work from Western Australia and therefore not tested for Queensland (NLWRA 2005).

In order to reduce the uncertainty and risk of using inappropriate indicators associated with both the current wetland indicators and those under development, a framework for monitoring wetlands needs to be assessed, and indicators identified. Scoping appropriate indicators and methods provides a means by which current or new wetland planning arrangements can be monitored, and the efficacy of on-ground works assessed.

# 1. Introduction

## 1.3 Project Objectives

The objectives of the Wetland Indicators Scoping Study project are to:

- review relevant national and international literature on wetland condition and extent indicators and methodology as they relate to monitoring;
- perform a scoping study to determine appropriate resource condition indicators and methodologies for wetland monitoring for different wetland types, commencing with the set of national indicators;
- identify existing monitoring programs and highlight areas where monitoring is deficient for Inventory Database requirements (temporal and spatial);
- identify resource condition parameters for inclusion in the Wetlands Inventory Database;
- identify criteria for resource condition monitoring as outlined in the Queensland Wetlands Programme Monitoring, Evaluation and Reporting Strategy;
- make recommendations for developing conceptual understandings of wetland types; and
- Consolidate links to other Queensland Wetlands Programme projects.

## 2. Methods

A major output of this project was an 'expert' workshop to 'determine appropriate indicators and methodologies'. In preparation for the workshop, a literature review of indicators of condition, methods used, and programs using these indicators was undertaken. The results of this review are in Section 3.

A 1½ day workshop to identify indicators and methodologies was run, attended by wetland experts from across Australia. The workshop concentrated on lacustrine, palustrine and groundwater wetlands in Queensland. It was acknowledged that other wetland types (riverine, marine and estuarine) are currently under investigation by other groups in Queensland, and there was little to be gained by addressing those wetlands in this forum. Information on riverine, estuarine and marine indicators and methodologies was gathered through direct one-on-one meetings between the project team and the proponents of those programs (Sections 7, 8, & 9).

The workshop was purposely designed so that deviations from the agenda could be tolerated in the interest of consensus on a framework for selecting indicators. This enabled issues that arose to be discussed, and the direction of the workshop to be fluid. The result was that, by the end of the workshop, a framework for identifying indicators (Section 6), and

a series of conceptual models had been developed (Sections 9.4). During the course of the workshop, some groups identified potential indicators for their particular wetland sub-type, but, in general, this was not an outcome of the workshop.

The minutes of the workshop were written into a report format and distributed for comment. The Workshop Report (Maher et al. 2006) is a direct record of the workshop (Attachment A), and any comment pertaining to issues related to the outcomes of the workshop, but not addressed at the workshop, have been included in the project report.

The final task of the project is to communicate the findings of the project to the relevant projects of the Queensland Wetlands Programme, the State agencies and regional bodies of Queensland.

# 3 Literature Search

The following literature search is a summary of programs, indicators and frameworks associated with wetland monitoring in Australia, as well as Australian reviews of wetland monitoring. Some of the programs are designed for one-off assessments e.g.

AquaBAMM, some are research based, whilst others are the basis of monitoring programs e.g. SEAP. Relevant international literature is also summarised. Where possible web links are provided in the text. Appendix 1 lists all the URLs from the literature search. This literature search was originally produced for this project and was further developed for the National Wetland Indicators Review project by the NLWRA (Conrick et al. 2007). Throughout the course of both projects the search has been developed to cater for the needs of each project. Much of the information presented in this section will also be reproduced in the report to NLWRA.

## 3.1 National resource condition indicators

From 1997 to 2002, the National Land & Water Resources Audit (NLWRA) coordinated the development of national Matters for Target (MfT) indicator headings and associated indicators and methodologies as part of the National NRM M&E Framework (NM&EF) through Monitoring and Evaluation Working Groups (MEWGs). The full list of Matters for Target and Indicator Headings are in Table 1. Wetlands, as defined by DIWA, are addressed under two Matters for Target: 'Inland aquatic ecosystem integrity', and 'Estuarine, coastal and marine habitats integrity'.

These Matters for Target have intuitively divided wetlands into the groups described by Cowardin et al. (1979): marine, estuarine, riverine, lacustrine and palustrine. Marine and estuarine wetlands are addressed under the 'Estuarine, coastal and marine habitats integrity' MfT, whilst freshwater and inland saline wetlands are dealt with by the 'Inland aquatic ecosystems integrity' MfT. Riverine wetlands are considered under the 'River condition' indicator heading, and lacustrine and palustrine wetlands under the 'Wetland ecosystem extent and distribution' and 'Wetland ecosystem condition' headings. The indicators for these headings, which are all under review, are in Table 2. Methods are available online.

Recent work by the NLWRA and the Queensland Department of Natural Resources and Mines (now NRW) on monitoring and evaluation trials of NLWRA indicators at a regional scale for the National Action Plan for Salinity and Water Quality (NAP)/Natural Heritage Trust indicated '...that only 15% of the recommended indicators and their methodology for monitoring are likely to be followed as proposed in the two study regions and almost half of the recommended indicators have methodological issues and are not likely to be monitored using the recommended framework.' In fact, wetland indicators did not make it on to the indicator list for consideration because of their perceived problems (NLWRA 2005).

The need for appropriate and realistic indicators and methodologies for all Matters for Target has been recognised, initiating reviews of current indicators and recommending new sets for the NRM M&E Framework.

## 3.2 Current programs and indicators in Australia

### Freshwater

Every State and Territory in Australia is currently undertaking monitoring of natural resource condition. Much of this work was initiated by the National River Health Program (NRHP) and the development of the AusRivAS models during the 1990s. It seeded the further development of wider-ranging indicators and the need to understand the systems that are under investigation. While the NRHP was directed towards rivers, there has not been a complementary development of monitoring in the lacustrine and palustrine wetland arena. At best, ad-hoc arrangements exist for monitoring these wetlands, and in many cases they are ignored because of the lack of suitable monitoring techniques.

The Australian River Assessment System (AusRivAS) uses rapid assessment techniques and predictive models to assess the ecological health of Australian rivers (Simpson *et al* 1997; Simpson and Norris 2000). It was developed under the NRHP by the Australian Government in response to a growing concern in Australia for maintaining ecological values, and is based on the British RIVPACS models (Wright 1993).

AusRivAS has two programs: Bioassessment, and Physical Assessment. These correspond respectively with rapid biological assessment protocols, and rapid geomorphic, physical and chemical assessment protocols. The indicators under each of these streams are in Table 3 (see page 9).

The most commonly used AusRivAS models predict the aquatic macroinvertebrate fauna expected to occur at a (reference) site in the absence of environmental stress, such as pollution or habitat degradation, to which the fauna collected at another (test) site can be compared. AusRivAS macroinvertebrate predictive models have been developed for each state and territory for the main habitat types found in Australian river systems, including riffle, edge, pool, and bed habitats.

AusRivAS is often used in conjunction with other macroinvertebrate indices to provide a more robust assessment of river health. The SIGNAL Index (Stream Invertebrate Grade Number – Average Level) is a simple scoring system of macroinvertebrate samples to assess water quality (Chessman 1995; 2003). Different macroinvertebrate taxa are known to display varying degrees of sensitivity to water pollution. Each taxon is allocated a grade of sensitivity to pollution, the grades are averaged for each sample and the index score plotted for interpretation. Other indices in use include the total taxa richness of a sample and EPT (or sensitive) taxa richness.

**Table 1. National Resource Condition Matters for Target.**

| Resource Condition Matters for Targets                           | Indicator Headings                                                                                                                                                           |
|------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Land salinity                                                    | <ul style="list-style-type: none"> <li>• Area of land threatened by shallow or rising water tables</li> </ul>                                                                |
| Soil condition                                                   | <ul style="list-style-type: none"> <li>• Soil condition</li> </ul>                                                                                                           |
| Native vegetation communities' integrity                         | <ul style="list-style-type: none"> <li>• Native vegetation extent and distribution</li> <li>• Native vegetation condition</li> </ul>                                         |
| Inland aquatic ecosystems integrity (rivers and other wetlands)  | <ul style="list-style-type: none"> <li>• River condition</li> <li>• Wetland ecosystem extent and distribution</li> <li>• Wetland ecosystem condition</li> </ul>              |
| Estuarine, coastal and marine habitats integrity                 | <ul style="list-style-type: none"> <li>• Estuarine, coastal and marine habitat extent and distribution</li> <li>• Estuarine, coastal and marine habitat condition</li> </ul> |
| Nutrients in aquatic environments                                | <ul style="list-style-type: none"> <li>• Nitrogen in aquatic environments</li> <li>• Phosphorus in aquatic environments</li> </ul>                                           |
| Turbidity / suspended particulate matter in aquatic environments | <ul style="list-style-type: none"> <li>• Turbidity / suspended solids</li> </ul>                                                                                             |
| Surface water salinity in freshwater aquatic environments        | <ul style="list-style-type: none"> <li>• In-stream salinity</li> </ul>                                                                                                       |
| Significant native species and ecological communities            | <ul style="list-style-type: none"> <li>• Selected significant native species and ecological communities extent and conservation status</li> </ul>                            |
| Ecologically significant invasive species                        | <ul style="list-style-type: none"> <li>• Selected ecologically significant invasive species extent and impact</li> </ul>                                                     |

# 3 Literature Search

**Table 2. Recommended indicators for wetland Matters for Target.**

| Indicator Heading                                                                                                            | Recommended Indicators                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| River Condition<br>(Indicator Status: For Advice)                                                                            | <p>For regionally significant reach based issues that is the subject of targets in regional plans, the indicators are:</p> <ul style="list-style-type: none"> <li>• Benthic macroinvertebrate community assemblages (Indicator Status: For Advice)</li> <li>• Fish community Assemblages (Indicator Status: For Advice)</li> <li>• Benthic diatom community assemblages (Indicator Status: For Advice)</li> <li>• Riparian vegetation community assemblages (Indicator Status: For Advice)</li> <li>• Riverine physical structure and in-stream habitat (Indicator Status: For Advice)</li> <li>• Water quality (Indicator Status: For Advice)</li> <li>• Hydrology (Indicator Status: For Advice)</li> </ul> <p>If all or most of these indicators are measured, it may be possible to use monitoring data to develop an index of river condition</p>                                                                                    |
| Wetland ecosystem extent and distribution                                                                                    | Extent of regionally significant wetlands (Indicator Status: Unclear)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Wetland ecosystem condition<br>(Indicator Status: For Advice)                                                                | <p>Condition of regionally significant wetlands based on:</p> <ul style="list-style-type: none"> <li>• Colour (Indicator Status: For Advice)</li> <li>• Dissolved oxygen and temperature (Indicator Status: For Advice)</li> <li>• Extent of inundation (Indicator Status: For Advice)</li> <li>• Macroinvertebrate diversity and community composition (Indicator Status: For Advice)</li> <li>• Macroinvertebrate index (Indicator Status: For Advice)</li> <li>• Macroinvertebrate indicator species (Indicator Status: For Advice)</li> <li>• Nutrients (Phosphorus and Nitrogen) (Indicator Status: For Advice)</li> <li>• Transparency (Indicator Status: For Advice)</li> <li>• Vegetation (Indicator Status: For Advice)</li> <li>• Phytoplankton (Indicator Status: For Advice)</li> </ul>                                                                                                                                       |
| Estuarine, coastal and marine habitat extent and distribution<br>(Indicator Status: For Advice)<br><br>(continued over page) | <ul style="list-style-type: none"> <li>• Algal blooms (Indicator Status: For advice)</li> <li>• Animal disease/lesions (Indicator status: for advice)</li> <li>• Animal kills (Indicator Status: For advice)</li> <li>• Animal or plant species abundance (Indicator Status: For advice)</li> <li>• Animals killed or injured by litter (entanglement, starvation, suffocation) (Indicator Status: For advice)</li> <li>• Benthic microalgae biomass (in intertidal sand/mudflat communities) (Indicator Status: For advice)</li> <li>• Biomass, or number per unit area, of epiphytes (in seagrass or mangrove communities) (Indicator Status: For advice)</li> <li>• Biomass, or number per unit area, of macroalgae (in rocky shore, rocky reef or coral reef communities) (Indicator Status: For advice)</li> <li>• Chlorophyll a (Indicator Status: For advice)</li> <li>• Coral bleaching (Indicator Status: For advice)</li> </ul> |

| Indicator Heading                                                                                                              | Recommended Indicators                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|--------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Estuarine, coastal and marine habitat extent and distribution<br>(Indicator Status: For Advice)<br><br>(continued from page 8) | <ul style="list-style-type: none"> <li>• Death of marine mammals, endangered sharks and reptiles caused by boat strike, shark nets or drum lines (Indicator Status: For advice)</li> <li>• Dissolved Oxygen (DO) (Indicator Status: For advice)</li> <li>• Estuary mouth opening/closing (Indicator Status: For advice)</li> <li>• Extent/distribution of key habitat types (Indicator Status: For advice)</li> <li>• Extent/distribution of subtidal macroalgae (Indicator Status: For advice)</li> <li>• Occurrence of imposex (Indicator Status: For advice)</li> <li>• Pest species (number, density, distribution) (Indicator Status: For advice)</li> <li>• pH (Indicator Status: For advice)</li> <li>• Presence/extent of litter (Indicator Status: For advice)</li> <li>• Salinity (Indicator Status: For advice)</li> <li>• Seagrass: depth range (Indicator Status: For advice)</li> <li>• Sedimentation/erosion rates (Indicator Status: For advice)</li> <li>• Targeted pathogen counts (Indicator Status: For advice)</li> <li>• Total nutrients in the sediment WITH dissolved nutrients in the sediment (Indicator Status: For advice)</li> <li>• Total nutrients in the water column WITH dissolved nutrients in the water column (Indicator Status: For advice)</li> <li>• Toxicants in biota (Indicator Status: For advice)</li> <li>• Toxicants in the sediment (Indicator Status: For advice)</li> <li>• Turbidity/water clarity (Indicator Status: For advice)</li> <li>• Water-current patterns (Indicator Status: For advice)</li> <li>• Water soluble toxicants in the water column (Indicator Status: For advice)</li> <li>• Water temperature (Indicator Status: For advice)</li> </ul> |
| Estuarine, coastal and marine habitat condition                                                                                | Condition of habitat at significant sites of selected estuarine, coastal and marine habitats (Indicator Status: Unclear)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |

**Table 3. AusRivAS indicators.**

| Indicator Heading   | Indicator                                                                                 |
|---------------------|-------------------------------------------------------------------------------------------|
| Bioassessment       | <ul style="list-style-type: none"> <li>• Macroinvertebrates</li> <li>• Diatoms</li> </ul> |
| Physical Assessment | <ul style="list-style-type: none"> <li>• Physical and Chemical Geoassessment</li> </ul>   |

### 3 Literature Search

AUSWAMP and SWAMPS are two biological assessment methods that were developed for Western Australian lacustrine and palustrine wetlands on the back of the AusRivAS and SIGNAL methods developed for rivers (Chessman et al. 2002; Davis et al. 1999; 2001; 2006). Despite being regionally limited to SW Western Australia, they are two of the currently recommended national indicators for wetlands. Geographical limitations, as well as the obvious requirement of a fairly advanced skill level, have restricted the use of these indicators by regional NRM bodies.

The AUSWAMP (Australian Wetlands Assessment and Monitoring Program) project developed monitoring protocols and rapid assessment methods for determining wetland health to assist diagnosis of wetland stress and performance measures for management, rehabilitation and restoration programs. The project determined the usefulness of applying methods developed as part of the NRHP (AusRivAS) to the monitoring and assessment of Australian lacustrine and palustrine wetlands. The model predicts the invertebrate community that would be expected to occur at a site if it is in reference condition. A comparison of the invertebrates predicted to occur with the actual occurrence provides a measure of biological damage. The paper describing this method (Davis et al. 2006) also assessed qualitative indices of wetland condition:

- Hydrology (change from seasonal to permanent water regime),
- Enrichment (degree of nutrient enrichment),
- Contaminants (degree of contamination of sediments with pesticides and heavy metals),
- Introduced fish (presence of the mosquito fish (*Gambusia*),
- Fringing vegetation (%) of undisturbed remnant vegetation within 100 m of wetland edge
- Groundwater abstraction (location of bore fields and approximate extraction volumes = index of potential impact).

The SWAMPS (Swan Wetlands Aquatic Macroinvertebrate Pollution Score) index is a biotic index using macroinvertebrates which can be used to provide an assessment of the health of selected wetlands on the Swan Coastal Plain in Western Australia. It was developed using the objective

iterative method of Chessman et al. (1997) for macroinvertebrate families of rivers in eastern Australia (SIGNAL). This work may be widely applicable across Australia, but will require adjustment to reflect local taxa distributions.

The National Water Commission (NWC) is overseeing the implementation of the National Water Initiative (NWI), a comprehensive strategy to improve water management across the country. The NWI Agreement, which has been signed by the Commonwealth and all States and Territories, is Australia's blueprint for national water reform. It encompasses a range of water management issues and encourages the adoption of best-practice approaches. The overall objective of the NWI is to achieve a nationally compatible market, regulatory and planning based system of managing surface and groundwater resources for rural and urban use that optimises economic, social and environmental outcomes.

The project 'Australian Water Resources 2005 (AWR)' (originally called the Baseline Assessment of Water Resources) is one of several projects funded to improve the knowledge and understanding of Australia's water resources under the 'Raising National Water Standards Programme' of the National Water Initiative (NWI website, accessed 24.1.07). It is being developed in extensive consultation with partner governments, to allow for the future application of a robust national assessment that utilises existing work to the maximum extent possible. There are three components to the project:

- Water availability,
- Water quality/river and wetland health, and
- Water use.

Under the water quality/river and wetland health component, the AWR will '...utilise existing river health assessments and develop a national framework for river health assessment...'. The project, entitled 'Framework for Comparable Assessment of the Ecological Condition of Australian Rivers and Wetlands' (FARWH) (Norris et al. 2007), is being developed to provide assessments of river and wetland health that can be reported at a national scale from comparable state- and territory-based assessments. It is intended that FARWH will incorporate a range of river and wetland attributes indicative of key ecological processes which will be aggregated to provide an index. This information will

assist managers to 'assess and develop policies, decide on investments, evaluate program and policy performance, and direct resource management' (Norris et al. 2007).

FARWH is based on the premise that ecological integrity is the fundamental measure of river and wetland health and, although the ultimate measure of that integrity is the damage to the biota, other components of the ecosystem are just as important, and should be included in an assessment of ecosystem health. It recommends selecting indicators under six themes: catchment disturbance, physical form, hydrological disturbance, water quality and soils, fringing zone, and aquatic biota, although the selection of specific indicators is left to the discretion of the investigator. The appendix of the document provides methods for indicators that may be used under the six themes. Many of these were developed for the NLWRA 1997-2002 (specifically related to rivers), although more contemporary indicators developed for the Sustainable Rivers Audit, the Index of Stream Condition and other programs are also included. A referential approach will be used to assess each indicator and the resulting indices will be aggregated and integrated to generate scores which can be reported and compared at the state and/or national level.

Waterbird populations are currently monitored through aerial surveys and processes are underway to standardise these methods. The East Asian-Australasian Shorebird Site Network (EAASSN) is an international cooperative effort to conserve and protect the major wetlands utilised by migrating shorebirds. Managers of the sites are encouraged to establish a local advisory or liaison group and develop management plans.

The Sustainable Rivers Audit (SRA) uses scientific indicators of health to determine the current ecological condition and health of river valleys in the Murray-Darling Basin (MDBC 2004). It will provide a better insight into the variability of river health indicators throughout the Basin and over time, and better inform management of the Basin. Three indicator themes are currently being monitored (fish, macroinvertebrates and hydrology) and others are under development (vegetation and physical form) for implementation in the future (Table 4).

**Table 4. Themes and indicators currently in use and being developed for the Sustainable Rivers Audit.**

| Theme Index                                                                                                           | Indicator                                                                                                                                                       |
|-----------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Fish (channel)                                                                                                        | <ul style="list-style-type: none"> <li>• Expected species</li> <li>• Nativeness</li> <li>• Diagnostic</li> </ul>                                                |
| Macroinvertebrates (channel)                                                                                          |                                                                                                                                                                 |
| Hydrology (channel)<br><br>(the indicators for this theme are those recommended from the Hydrology Pilot SRA Program) | <ul style="list-style-type: none"> <li>• High Flow</li> <li>• Low and Zero Flow</li> <li>• Variability</li> <li>• Seasonality</li> <li>• Flow volume</li> </ul> |
| Vegetation (channel and floodplain)                                                                                   | This index is under development                                                                                                                                 |
| Physical Form (channel and floodplain)                                                                                | This index is under development                                                                                                                                 |

### 3 Literature Search

Whilst the current themes are targeting in-stream habitats, those under development will encompass wetlands on the floodplain as well as the channel. Information gained through the SRA monitoring of condition will assist in setting targets and developing strategies to improve the management of rivers, and the monitoring against those targets and strategies. The Audit will detect large scale change providing a standard framework across the Basin for comparing information.

In Tasmania, the Conservation of Freshwater Ecosystem Values (CFEV) project was initiated to identify where important freshwater values exist on Crown and private land, and to identify a full range of management tools to conserve those values. This information is stored in a database which acts as a planning and information tool for management purposes and includes the identification and conservation of values that exist within Tasmania's rivers and streams, wetlands, lakes, estuaries, saltmarshes, karst systems and groundwater dependent ecosystems.

**Table 5. Sub-indices and variables identified for the 2004 benchmark Victorian Index of Stream Condition (DSE 2005a).**

| ISC sub-index   | Measure                                                                                                                                                                                                                                               |
|-----------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Hydrology       | <ul style="list-style-type: none"> <li>• Low flows</li> <li>• High flows</li> <li>• Zero flows</li> <li>• Seasonality</li> <li>• Variability</li> </ul>                                                                                               |
| Water quality   | <ul style="list-style-type: none"> <li>• Total Phosphorus</li> <li>• Turbidity</li> <li>• Salinity (EC)</li> <li>• pH</li> </ul>                                                                                                                      |
| Streamside zone | <ul style="list-style-type: none"> <li>• Width</li> <li>• Longitudinal continuity</li> <li>• Understorey diversity</li> <li>• Recruitment</li> <li>• Large trees</li> <li>• Tree canopy</li> <li>• Litter</li> <li>• Logs</li> <li>• Weeds</li> </ul> |
| Physical form   | <ul style="list-style-type: none"> <li>• Bank stability</li> <li>• Large wood</li> <li>• Fish passage</li> </ul>                                                                                                                                      |
| Aquatic life    | <ul style="list-style-type: none"> <li>• AusRiVAS (habitat)</li> <li>• SIGNAL (pollution)</li> </ul>                                                                                                                                                  |

Victoria has developed two indices of aquatic condition, the Index of Stream Condition (ISC) and the Index of Wetland Condition (IWC) to assist Catchment Management Authorities (CMAs) to set management objectives and measure the effectiveness of long term programs.

The ISC is an index of environmental condition integrating information on the major components of our river systems that are important from an ecological perspective (flow regime, water quality, geomorphology and biota of rivers). It provides an overall indication of changes in river condition and assesses the condition of homogenous river reaches to assist with the delivery of stream management programs in Victoria, in particular in priority setting, resource allocation, assessing management effectiveness and setting benchmarks (Ladson & White 1999). The sub-indices and variables were updated for the second benchmark ISC report in 2004 (Table 5) from those used in the initial report in 1999 (DSE 2005a).

The Index of Wetland Condition (IWC) is a rapid assessment technique which aims to differentiate natural from human-induced changes in condition (DSE 2005b). It applies to naturally occurring, v non-flowing wetlands which do not have a marine hydrological influence and, similarly to the ISC, takes the form of a hierarchical index with six sub-indices based on the characteristics that define wetlands: wetland catchment, physical form, hydrology, soils, water properties and biota. The sub-indices and measures are listed in Table 6. The IWC is currently undergoing trials in Victoria.

**Table 6. Sub-indices and measures for the Victorian Index of Wetland Condition (DSE 2005b).**

| IWC sub-index     | Measure                                                                                                                                                                                                                                                                                                                             |
|-------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Wetland catchment | <ul style="list-style-type: none"> <li>• Percentage of land in different land use intensity classes adjacent to the wetland</li> <li>• Average width of the buffer</li> <li>• Percentage of wetland perimeter with a buffer</li> </ul>                                                                                              |
| Physical form     | <ul style="list-style-type: none"> <li>• Percentage reduction in wetland area</li> <li>• Percentage of wetland where activities (excavation and landforming) have resulted in a change in bathymetry</li> </ul>                                                                                                                     |
| Hydrology         | <ul style="list-style-type: none"> <li>• Severity of activities that change the water regime</li> </ul>                                                                                                                                                                                                                             |
| Water properties  | <ul style="list-style-type: none"> <li>• Activities leading to an input of nutrients to the wetland</li> <li>• Factors likely to lead to wetland salinisation:               <ul style="list-style-type: none"> <li>o input of saline water to the wetland</li> <li>o wetland occurs in a salinity risk area</li> </ul> </li> </ul> |
| Soils             | <ul style="list-style-type: none"> <li>• Percentage and severity of wetland soil disturbance</li> </ul>                                                                                                                                                                                                                             |
| Biota             | <ul style="list-style-type: none"> <li>• Wetland vegetation quality assessment based on:               <ul style="list-style-type: none"> <li>o critical lifeforms</li> <li>o presence of weeds</li> <li>o indicators of altered processes</li> <li>o vegetation structure and health</li> </ul> </li> </ul>                        |

### 3 Literature Search

A rapid assessment method to monitor the condition of floodplain wetlands in the Murray-Darling Basin was developed in the late 90s (Spencer et al. 1998). It gave details of indicators to monitor soils, fringing vegetation, aquatic vegetation and water quality (Table 7). This report did not give rise to any major monitoring program, although it has been cited frequently in the literature (D. Baldwin pers. comm.).

WetlandCare Australia has developed an assessment manual which standardises and streamlines wetland assessment, allowing the formation of regional, and possibly national, comparative databases that can be used as part of a Decision Support System to prioritise wetland investment by regional bodies (Golus et al. 2006). The methods described use rapid assessment techniques to monitor wetland health based primarily upon vegetation characteristics (Table 8). It allows rapid identification of changes in wetland health and timely implementation of impact monitoring, and protection or restoration measures.

The Freshwater Ecosystem Health Monitoring Program (Freshwater EHMP) (SE Queensland) was established to provide an objective assessment of the health of waterways throughout the southeast region (Abal et al. 2005). The information collected is used to advise councils and land managers on areas of declining health, report on the effects of different land uses, and to evaluate the effectiveness of management actions aimed at improving and protecting aquatic ecosystems. Comprehensive indicators were developed that relate aquatic health to disturbance pressures in Southeast Queensland through themes of fish, invertebrates, physico-chemical, eco-processes and nutrients. (Table 9) (Smith & Storey 2000).

**Table 7. Indicators proposed by Spencer et al. (1998) to monitor the condition of floodplain wetlands of the Murray-Darling Basin.**

| Indicator Heading   | Indicator                                                                                                                           |
|---------------------|-------------------------------------------------------------------------------------------------------------------------------------|
| Soil                | <ul style="list-style-type: none"><li>• Bank stability</li><li>• Pugging by livestock</li><li>• Soil organic content</li></ul>      |
| Fringing vegetation | <ul style="list-style-type: none"><li>• Width</li><li>• Continuity</li><li>• Height diversity</li></ul>                             |
| Aquatic vegetation  | <ul style="list-style-type: none"><li>• Cover</li><li>• Spatial heterogeneity</li><li>• Attached algae</li></ul>                    |
| Water               | <ul style="list-style-type: none"><li>• Turbidity</li><li>• Conductivity</li><li>• Colour</li><li>• Algal bloom frequency</li></ul> |

**Table 8. Indices and measures used by the WetlandCare Wetland Assessment Technique**

| Wetland Type             | Index                         | Indicators                                                                                                                                                                                      |
|--------------------------|-------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| All Wetlands             | Connectivity                  | <ul style="list-style-type: none"> <li>Proximity</li> <li>Area</li> <li>Roads</li> <li>Adjacent landuse</li> </ul>                                                                              |
|                          | Human Disturbance             |                                                                                                                                                                                                 |
|                          | Acid Sulphate Soils           |                                                                                                                                                                                                 |
| Paperbark Wetlands       | Paperbark condition           | <ul style="list-style-type: none"> <li>Vine growth</li> <li>Galls</li> <li>Standing dead or dying trees</li> <li>Clusters of fallen trees</li> <li>Necrotic spots</li> </ul>                    |
|                          | Wetland establishment         | <ul style="list-style-type: none"> <li>Girth circumference</li> <li>Depth of peat layer</li> </ul>                                                                                              |
| Open Freshwater Wetlands | Fringing Vegetation           | <ul style="list-style-type: none"> <li>Width</li> <li>Diversity</li> <li>Species number</li> <li>Weed</li> </ul>                                                                                |
|                          | Bank condition                | <ul style="list-style-type: none"> <li>Erosion</li> <li>Pugging</li> <li>Bank gradient</li> </ul>                                                                                               |
|                          | Water quality                 | <ul style="list-style-type: none"> <li>pH</li> <li>Turbidity</li> <li>Electrical conductivity</li> <li>Nitrate</li> <li>Ammonium</li> <li>Phosphate</li> </ul>                                  |
| Estuarine Wetlands       | Mangrove condition            | <ul style="list-style-type: none"> <li>Foliage cover</li> <li>Foliage health</li> <li>Community structure</li> </ul>                                                                            |
|                          | Saltmarsh condition           | <ul style="list-style-type: none"> <li>Ground cover</li> <li>Crab burrows</li> <li>Snail density</li> <li>Necrosis</li> <li>Mangrove &amp; terrestrial, freshwater weed encroachment</li> </ul> |
|                          | Tidal restriction & hydrology | <ul style="list-style-type: none"> <li>Mapped changes</li> <li>Presence of structures affecting tide</li> <li>Vegetation indicators</li> </ul>                                                  |

### 3 Literature Search

**Table 9. Indicators and measures used in the Queensland Freshwater Ecosystem Health Monitoring Program.**

| Indicator                  | Measure                                                                                                                                                                                        |
|----------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Physical/chemical          | <ul style="list-style-type: none"> <li>• pH</li> <li>• Conductivity</li> <li>• Diel (24hr) range and maximum temperature</li> <li>• Diel range and minimum dissolved oxygen</li> </ul>         |
| Nutrient cycling           | <ul style="list-style-type: none"> <li>• Ratio of 15N to 14N stable isotope</li> <li>• Algal bioassay</li> </ul>                                                                               |
| Ecosystem processes        | <ul style="list-style-type: none"> <li>• Growth rate of algae</li> <li>• Ratio of 13C to 12C stable isotopes</li> <li>• Respiration (R24)</li> <li>• Gross Primary Production (GPP)</li> </ul> |
| Aquatic macroinvertebrates | <ul style="list-style-type: none"> <li>• Number of macroinvertebrate taxa</li> <li>• EPT richness (number of stonefly, mayfly and caddisfly families)</li> <li>• SIGNAL score</li> </ul>       |
| Fish                       | <ul style="list-style-type: none"> <li>• Proportion of native species expected</li> <li>• Ratio of observed to expected species</li> <li>• Proportion of alien fish</li> </ul>                 |

The Dryland Refugia project (2001-2005), run by the now concluded Cooperative Research Centre for Freshwater Ecology (CRCFE), sampled three Queensland river systems (Cooper Creek, Warrego River and the Border Rivers) to determine the relationships between biodiversity and the physical attributes of individual waterholes as well as the spatial and temporal pattern of connectivity in the landscape. The biophysical processes that sustained biodiversity and ecosystem health in dryland river refugia were also identified. The principal outcomes from the project related to understanding how changes in hydrology and land management influence the biological and physical processes and integrity of refugia. This information was intended to be usable in other arid and semi-arid regions of Australia. Many variables covering geomorphology, hydrology, and water quality were collected during the course of the project (Table 10) (Marshall et al 2006a). In addition, fish, macroinvertebrates, macrophytes, algae, and biophysical processes were also sampled.

\* only those WQ parameters used in the analyses are listed

The Narran Lakes system has been under investigation since 2003, initially by the CRC Freshwater Ecology, and now eWater. The project is investigating ecosystems responses to flow variability in the Narran Lakes floodplain-wetland complex. A series of conceptual models of the key ecological functioning of Narran Lakes has enabled the identification of knowledge gaps and is working towards increasing the understanding of terminal floodplain-wetlands in the semi-arid region of Australia. This knowledge will allow the response of these types of systems to disturbances, both natural and those induced by continued water resource and floodplain development, to be predicted.

**Table 10. Variables measured in the Dryland Refugia project (Marshall et al. 2006a).**

| Variable class              | Variables                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|-----------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Floodplain morphology       | <ul style="list-style-type: none"> <li>• Total flood plain width</li> <li>• Effective flood plain width</li> <li>• Flood plain setting</li> <li>• Bifurcation ratio</li> <li>• Number of channels</li> <li>• Channel distance to the nearest waterhole</li> <li>• Straight line distance to the nearest waterhole</li> </ul>                                                                                                                                                   |
| Waterhole morphology        | <ul style="list-style-type: none"> <li>• Surface Area</li> <li>• Perimeter</li> <li>• Length</li> <li>• Width</li> <li>• Fetch length</li> <li>• Circularity</li> <li>• Elongation ratio</li> <li>• Length to width ratio</li> <li>• Width to depth ratio</li> <li>• Hydraulic radius</li> <li>• Wetted perimeter</li> <li>• Shape index</li> <li>• Depth of cross-section</li> <li>• Volume</li> </ul>                                                                        |
| Within waterhole morphology | <ul style="list-style-type: none"> <li>• Mid-channel bars</li> <li>• Backwater</li> <li>• Offtake channels</li> <li>• Bench 0 – 1/3</li> <li>• Bench 1/3 – 2/3</li> <li>• Bench 2/3 – 3/3</li> <li>• Side bars</li> <li>• Miscellaneous bars</li> <li>• Anabranches</li> <li>• Bed and bank complexity</li> <li>• Eroding banks</li> <li>• Snag density</li> <li>• Scour holes</li> <li>• Boulders</li> <li>• Fringing vegetation</li> <li>• Overhanging vegetation</li> </ul> |

continued on next page

### 3 Literature Search

Table 10 continued from previous page

| Variable class | Variables                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|----------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Sample habitat | <ul style="list-style-type: none"> <li>• % deep (not sampleable)</li> <li>• % edge</li> <li>• % silt/clay pool</li> <li>• % sandy pool</li> <li>• % rocky pool</li> <li>• Edge algae density</li> <li>• Edge detritus density</li> <li>• Edge macrophyte density</li> <li>• Rocks</li> <li>• Mean wetted width</li> </ul>                                                                                                                                                  |
| Water quality* | <ul style="list-style-type: none"> <li>• Conductivity</li> <li>• Turbidity</li> <li>• Total nitrogen</li> <li>• Ratio total N: total P</li> <li>• Dissolved oxygen 24 hr minimum</li> <li>• Water temperature 24 hr maximum</li> <li>• Silicate</li> <li>• Sulphate</li> </ul>                                                                                                                                                                                             |
| Hydrology      | <ul style="list-style-type: none"> <li>• Time since discharge &gt;1500 ML/day</li> <li>• Time since discharge &gt;1000 ML/day</li> <li>• Time since discharge &gt;500 ML/day</li> <li>• Time since discharge &gt;50 ML/day</li> <li>• Total antecedent discharge in past 90 days</li> <li>• Total antecedent discharge in past 60 days</li> <li>• Total antecedent discharge in past 30 days</li> <li>• Duration of most recent high flow event &gt; 500 ML/day</li> </ul> |

The State of the Rivers projects provide ‘snapshots’ of the ecological and physical condition of streams (Anderson 1993). It is currently undertaken in Queensland by the Department of Natural Resources and Water. The program aims to provide an assessment of the physical and environmental condition of streams at the time of survey, relative to their presumed natural or original condition. The approach focuses on the attributes recognised as being important to instream and riparian fauna and flora, and is designed to be independent of flow conditions and water levels at the time of survey. Intensive surveys are carried out on a catchment by catchment basis and the data is then analysed to determine individual and overall condition ratings.

Indices measured are:

- Reach environs condition
- Bank condition
- Bed and bar condition
- Channel habitat diversity
- Riparian vegetation condition
- Aquatic vegetation condition
- Aquatic habitat condition
- Scenic and recreational value
- Conservation value.

The Rapid Appraisal of Riparian Condition (RARC) and the Tropical Rapid Appraisal of Riparian Condition (TRARC) are methods that have been developed to assess the health of riverine riparian zones (Jansen et al 2005; Dixon et al. 2006). Both methods derive an index of condition using indicators to reflect functional aspects of the physical, community and landscape features of the riparian zone. The resulting indices will inform land managers on the condition of their riparian zones and assist in their management. Whilst the indices are not designed nor recommended for lacustrine and palustrine wetlands, some of the indicators may be useful in assessing those wetlands. The sub-indices and indicators for both assessments are listed in Tables 11 and 12.

AquaBAMM is a decision support method developed by the Queensland EPA that utilises existing information and expert input to assess conservation values in aquatic ecosystems. To date the method has only been developed and trialled fully in riverine

wetlands, although the program is currently being applied to non-riverine wetlands (Clayton et al. 2006). Future work will extend the program to estuarine and marine systems as well as rapid assessment of freshwater systems. Whilst not strictly a method for determining resource condition, rather a method for determining conservation values of sites and catchments, criteria, indicators and measures are identified in the method. Table 13 lists the default riverine and non-riverine indicators. Up to 14 measures are identified under each indicator. Data for all of the diagnostic measures are sourced from available databases.

The Riverstyles® method is a geomorphic system to classify rivers, based on the direct link between vegetative and geomorphic processes, providing an assessment of habitat availability along river courses, and hence indirect linkage to river ecology (Brierley et al. 2002; 2005). It is also the basis of the Physical Assessment component of AusRivAS. Indicators are listed in Table 14.

Waterwatch is a nation-wide program for community and landholder/managers to be actively involved in monitoring wetland condition. Modified tests or methods are used to conduct biological, physico-chemical and habitat assessments to build a picture of the health of waterways and catchments. The Waterwatch Australia national technical manual is available from the web.

In addition to the programs summarised above, each state/territory is involved in monitoring in lacustrine and palustrine wetlands, albeit in some instances, on an ad hoc basis. In many cases wetlands are addressed through other natural resource monitoring programs e.g. vegetation, salinity, The Living Murray, TasVeg, etc. Wetlands are also monitored by regional groups (NRM bodies, CMAs) as part of their programs. Indicators most often measured include water birds, water quality, vegetation, crocodiles and feral animals (in the Northern Territory), and macroinvertebrates (in Western Australia).

Within the Ramsar wetland network, ecological character description work is being undertaken and in some cases very detailed assessments and descriptions are being completed. These may provide information that can support baseline or reference condition descriptions against which indicators can be assessed.

### 3 Literature Search

**Table 11. RARC sub-indices and indicators.**

| Sub-Index | Indicator                                                                                                                                                                                                              |
|-----------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Habitat   | <ul style="list-style-type: none"> <li>• Longitudinal continuity of riparian vegetation</li> <li>• Width of riparian vegetation</li> <li>• Proximity to nearest patch of intact native vegetation</li> </ul>           |
| Cover     | <ul style="list-style-type: none"> <li>• Canopy (&gt;5 m tall)</li> <li>• Understorey (1-5 m tall)</li> <li>• Ground (&lt; 1 m tall)</li> <li>• Number of layers</li> </ul>                                            |
| Natives   | <ul style="list-style-type: none"> <li>• Canopy (&gt; 5 m tall)</li> <li>• Understorey (1-5 m tall)</li> <li>• Ground (&lt; 1 m tall)</li> </ul>                                                                       |
| Debris    | <ul style="list-style-type: none"> <li>• Leaf litter</li> <li>• Native leaf litter</li> <li>• Standing dead trees (&gt; 20 cm dbh*)</li> <li>• Hollow-bearing trees</li> <li>• Fallen logs (&gt;10 cm dbh*)</li> </ul> |
| Features  | <ul style="list-style-type: none"> <li>• Native canopy species regeneration (&lt;1 m tall)</li> <li>• Native understorey regeneration</li> <li>• Large native tussock grass</li> <li>• Reeds</li> </ul>                |

\* Diameter at breast height

**Table 12. TRARC sub-indices and indicators.**

| Sub-Index    | Indicator                                                                                                                                                                                                                                             |
|--------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Plant Cover  | <ul style="list-style-type: none"> <li>• Canopy cover</li> <li>• Canopy continuity</li> <li>• Midstorey cover</li> <li>• Understorey cover</li> <li>• Grass cover</li> <li>• Organic litter</li> <li>• Logs</li> </ul>                                |
| Regeneration | <ul style="list-style-type: none"> <li>• Canopy health</li> <li>• Large trees</li> <li>• Tree size classes</li> <li>• Dominant tree regeneration</li> <li>• Other tree regeneration</li> </ul>                                                        |
| Weeds        | <ul style="list-style-type: none"> <li>• Canopy weeds</li> <li>• Midstorey weeds</li> <li>• Understorey weeds</li> <li>• Grass weeds</li> <li>• Organic litter weeds</li> <li>• High impact weeds</li> <li>• High impact weed distribution</li> </ul> |
| Erosion      | <ul style="list-style-type: none"> <li>• Exposed soil</li> <li>• Exposed tree roots</li> <li>• Slumping</li> <li>• Gullyng</li> <li>• Undercutting</li> </ul>                                                                                         |
| Pressure     | <ul style="list-style-type: none"> <li>• Bank stability</li> <li>• Animals: managed and unmanaged</li> <li>• Fire</li> <li>• Tree clearing</li> <li>• Flow regime</li> <li>• Other</li> </ul>                                                         |

### 3 Literature Search

**Table 13. AquaBAMM criteria and indicators for riverine and non-riverine wetlands.**

| AquaBAMM Criteria                                   | Indicators                                                                                                                                                                                                                                                   |
|-----------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Naturalness Aquatic<br>(Diagnostic)                 | <ul style="list-style-type: none"> <li>• Exotic flora/fauna</li> <li>• Aquatic communities/assemblages</li> <li>• Habitat features modification</li> <li>• Hydrological modification</li> <li>• Water quality</li> </ul>                                     |
| Naturalness Catchment<br>(Diagnostic)               | <ul style="list-style-type: none"> <li>• Exotic flora/fauna</li> <li>• Riparian disturbance</li> <li>• Catchment disturbance</li> <li>• Flow modification</li> </ul>                                                                                         |
| Diversity and Richness<br>(Diagnostic)              | <ul style="list-style-type: none"> <li>• Species</li> <li>• Communities/assemblages</li> <li>• Habitat</li> <li>• Geomorphology</li> </ul>                                                                                                                   |
| Threatened Species and Ecosystems<br>(Diagnostic)   | <ul style="list-style-type: none"> <li>• Species</li> <li>• Communities/assemblages</li> </ul>                                                                                                                                                               |
| Priority Species and Ecosystems<br>(Expert opinion) | <ul style="list-style-type: none"> <li>• Species</li> <li>• Ecosystems</li> </ul>                                                                                                                                                                            |
| Special Features<br>(Expert opinion)                | <ul style="list-style-type: none"> <li>• Geomorphic features</li> <li>• Ecological processes</li> <li>• Habitat</li> <li>• Hydrological</li> </ul>                                                                                                           |
| Connectivity<br>(Expert opinion)                    | <ul style="list-style-type: none"> <li>• Significant species or populations</li> <li>• Groundwater dependent ecosystems</li> <li>• Floodplain and wetland ecosystems</li> <li>• Terrestrial ecosystems</li> <li>• Estuarine and marine ecosystems</li> </ul> |
| Representativeness<br>(Diagnostic)                  | <ul style="list-style-type: none"> <li>• Wetland protection</li> <li>• Wetland uniqueness</li> </ul>                                                                                                                                                         |

**Table 14. Catchment, reach and geomorphic unit characteristics measured in the Geomorphic River Styles method. After Brierley *et al.* (1996).**

| Characteristics        | Indicator                                                                                                                                                                                                                 |
|------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Catchment</b>       |                                                                                                                                                                                                                           |
| Relief measures        | <ul style="list-style-type: none"> <li>• Catchment relief</li> <li>• Catchment relief ratio</li> <li>• Longitudinal profile</li> <li>• Valley side slope length and angle</li> </ul>                                      |
| Areal properties       | <ul style="list-style-type: none"> <li>• Catchment area</li> <li>• Drainage pattern</li> <li>• Elongation ratio</li> <li>• Drainage density</li> </ul>                                                                    |
| Linear measurements    | <ul style="list-style-type: none"> <li>• Stream order</li> <li>• Stream length</li> </ul>                                                                                                                                 |
| Other measures         | <ul style="list-style-type: none"> <li>• Geology</li> <li>• Average annual rainfall and monthly averages</li> <li>• Landuse</li> <li>• Vegetation distribution and type</li> <li>• Discharge</li> </ul>                   |
| <b>Reach</b>           |                                                                                                                                                                                                                           |
| Channel planform       | <ul style="list-style-type: none"> <li>• Planform geometry</li> <li>• Radius of channel curvature to mean channel width ratio (rc/w)</li> <li>• Meander wavelength</li> <li>• Type of geomorphic units present</li> </ul> |
| Confinement            | <ul style="list-style-type: none"> <li>• Valley width</li> <li>• Degree and character of channel constriction</li> <li>• Terrace character</li> </ul>                                                                     |
| Vegetation character   | <ul style="list-style-type: none"> <li>• Percent coverage</li> </ul>                                                                                                                                                      |
| <b>Geomorphic Unit</b> |                                                                                                                                                                                                                           |
| Identification         | <ul style="list-style-type: none"> <li>• Within channel units</li> <li>• Channel marginal units and bank character</li> <li>• Floodplain units</li> </ul>                                                                 |

continued on next page

### 3 Literature Search

Table 14 continued from previous page

| Characteristics                                                      | Indicator                                                                                                                                                                                                                                  |
|----------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Morphology and dimensions of geomorphic units                        | <ul style="list-style-type: none"> <li>• Shape and size</li> <li>• Channel geometry</li> <li>• Channel bed elevation</li> <li>• Width to depth ratio</li> </ul>                                                                            |
| Hydraulic parameters                                                 | <ul style="list-style-type: none"> <li>• Flow character</li> <li>• Mannings roughness coefficient (n)</li> <li>• Froude number</li> </ul>                                                                                                  |
| Vegetation character                                                 | <ul style="list-style-type: none"> <li>• Vegetation cover dimensions</li> <li>• Vegetation composition</li> </ul>                                                                                                                          |
| Assemblage and connectivity of geomorphic units throughout the reach | <ul style="list-style-type: none"> <li>• Spatial character of geomorphic units</li> <li>• Channel – floodplain relationship</li> </ul>                                                                                                     |
| Lateral stability of the channel                                     | <ul style="list-style-type: none"> <li>• Degree and character of channel obstruction</li> <li>• Stream power</li> <li>• Bankfull discharge</li> </ul>                                                                                      |
| Sediment attributes                                                  | <ul style="list-style-type: none"> <li>• Grain size and distribution</li> <li>• Sorting</li> <li>• Rounding</li> <li>• Facies / sedimentary structures</li> <li>• Sediment mix and degree of packing</li> <li>• Type of grading</li> </ul> |
| Sediment relations                                                   | <ul style="list-style-type: none"> <li>• Degree of sediment storage</li> <li>• Sediment yield or sediment delivery ratio (SDR)</li> </ul>                                                                                                  |

## Marine and estuarine

Similarly to the freshwater component of the Ecosystem Health Monitoring Program (EHMP), the Marine and Estuarine EHMP undertakes regular monitoring of indicators such as water quality, seagrass depth range, coral monitoring, and nitrogen tracking in the marine and estuarine waters in southeast Queensland.

The recently concluded Cooperative Research Centre for Coastal Zone, Estuary and Waterway Management (The Coastal CRC) developed decision-making tools, understanding, and knowledge for the effective management and ecosystem health of Australia's coastal zone (inland extent of tidal influence to the extent of resource use and management in the near coastal waters), estuaries and waterways. The CRC linked terrestrial and marine issues, rural and urban issues, and industrial and recreational activities. Many of the partner organisations were Queensland based, and two of the three catchments used as study areas were in Queensland (Fitzroy and Moreton Bay). OzCoasts (<http://www.coastal.crc.org.au/ozcoast/index.html>) and OzEstuaries (<http://www.ozestuaries.org/>) are two of the tools developed, providing comprehensive information about Australian estuaries and coastal zone, including conceptual models, guides to indicators and methodologies and decision support tools.

Conceptual models depicting processes and threats to estuarine wetlands were also developed (<http://www.coastal.crc.org.au/wetlands/index.html>). These models are currently being updated and used in the testing phase of the national Matters for Target indicators review for Estuarine, coastal and marine habitats integrity, as well as the development of the estuarine component of the Department of Natural Resources and Water's Stream and Estuarine Assessment Program (SEAP). More detail is provided in Section 8.

Wetlands.edu is a national wetland education and management training program designed to provide capacity building and skills development for regional and community investments in wetland-related assessment, planning and actions, supported by funding from the Natural Heritage Trust. It is aimed primarily at regional natural resource management and catchment bodies and their stakeholders, including Landcare and river management groups,

local governments and private landholders (Wetland.edu website, accessed 19.6.07).

## Marine, estuarine and freshwater

Each State and Territory, and the Australian Government are obliged to report on the condition of the environment within their jurisdiction on a regular basis. In addition to State of the Environment (SoE) reporting they must also evaluate the effectiveness of environmental policies and provide environmental information to the public. The themes and indicators are selected from a core set of indicators determined by the State of the Environment Reporting Task Force of the Australian and New Zealand Environment and Conservation Council (ANZECC 2000). Riverine, lacustrine, palustrine, and subterranean wetlands are addressed under the theme of Inland Waters, and marine and estuarine wetlands under Estuaries & the Sea/Coastal Zone in Commonwealth and Queensland reporting (Table 15) (EPA 2005a).



# 3 Literature Search

**Table 15. ANZECC core environmental indicators, Commonwealth State of the Environment 2006, and Queensland State of the Environment 2003 wetland indicators.**

| ANZECC Core Environmental Indicators—inland waters                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p><b>Groundwater</b></p> <ul style="list-style-type: none"> <li>• IW_1 Groundwater extraction versus availability</li> <li>• IW_2 Exceedances of groundwater quality guidelines</li> </ul> <p><b>Surface water</b></p> <ul style="list-style-type: none"> <li>• IW_3 Extent of deep-rooted vegetation cover by catchment</li> <li>• IW_4 Surface water extraction versus availability</li> <li>• IW_5 Environmental flows objectives</li> <li>• IW_6 Discharges from point sources</li> <li>• IW_7 Surface water salinity</li> <li>• IW_8 Exceedances of surface water quality guidelines</li> <li>• IW_9 Freshwater algal blooms</li> <li>• IW_10 Waste water treatment (inland waters)</li> <li>• IW_11 Waste water re-use (inland waters)</li> </ul> <p><b>Aquatic habitats</b></p> <ul style="list-style-type: none"> <li>• IW_12 Vegetated streamlength</li> <li>• IW_13 River health (AusRivAS)</li> <li>• IW_14 Extent and condition of wetlands</li> <li>• IW_15 Estimated freshwater fish stock</li> </ul> |
| Estuaries and the Sea                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| <p><b>Marine habitat and biological resources</b></p> <ul style="list-style-type: none"> <li>• E+S_1 Changes in coastal use</li> <li>• E+S_2 Disturbance of marine habitat</li> <li>• E+S_3 Total seafood catch</li> <li>• E+S_4 estimated wild fish stocks</li> </ul> <p><b>Estuarine and marine water quality</b></p> <ul style="list-style-type: none"> <li>• E+S_5 Coastal discharges</li> <li>• E+S_6 Maritime pollution incidents</li> <li>• E+S_7 Exceedances of marine and estuarine water quality guidelines</li> <li>• E+S_8 Bio-accumulated pollutants</li> <li>• E+S_9 Algal blooms in estuarine and marine environments</li> <li>• E+S_10 Waste water treatment (coastal waters)</li> <li>• E+S_11 Disturbance of potential acid sulphate soils</li> </ul>                                                                                                                                                                                                                                              |
| <p><b>Global processes</b></p> <ul style="list-style-type: none"> <li>• E+S_12 Sea level</li> <li>• E+S_13 Sea surface temperature</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |

### Commonwealth State of the Environment (2006)—inland waters

#### Catchment Scale influences

- Influence of climate variability and change
  - o A\_01 Annual variations in the Southern Oscillation Index
  - o A\_02 Rainfall trends – annual mean rainfall
  - o A\_03 Rainfall extremes – inter-annual variations in annual extreme rainfall
  - o A\_04 Temperature trends – annual mean temperature anomalies
  - o A\_05 Temperature extremes – percentage area of extreme annual mean temperatures
  - o A\_06 Extreme weather-related effects – cost of weather-related disasters

#### Hydrological condition

- Surface-water availability and human use
  - o IW\_01 Annual river discharge
  - o IW\_02 Annual water storage
  - o IW\_03 Surface water used for irrigation
  - o IW\_04 Surface water used for urban/industrial
- Ground-water availability and human use
  - o IW\_05 Average annual groundwater depth
  - o IW\_06 Average annual groundwater pressure
  - o IW\_07 Groundwater impact on river flows – base flow index
  - o IW\_08 Groundwater used for irrigation
  - o IW\_09 Groundwater used for urban/industrial
  - o BD-08 Change in area and proportion of woody native vegetation
  - o IW\_44 Sustainable yield determination

continued on next page

# 3 Literature Search

Table 15 continued from previous page

| Commonwealth State of the Environment (2006)—inland waters                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <ul style="list-style-type: none"> <li>• Ecological aspects of river flow regimes               <ul style="list-style-type: none"> <li>o IW_10 Assessment of River Condition indices</li> <li>o IW_11 Number of licences dams, weirs, regulators and levees</li> <li>o IW_26 Length of intact riparian zone &gt;50-100 m wide</li> <li>o IW_27 Condition of significant wetlands</li> <li>o IW_28 Number of effective fishways</li> <li>o IW_46 Implementation of COAG principles</li> </ul> </li> <li>• Connectivity – dams, weirs, regulators and levees               <ul style="list-style-type: none"> <li>o IW_11 Number of licences dams, weirs, regulators and levees</li> </ul> </li> </ul>                                                                                                                                                                                                                                                                                       |
| <b>Land and vegetation condition</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| <ul style="list-style-type: none"> <li>• Erosion               <ul style="list-style-type: none"> <li>o LD_04 Exposed soil surface contributing to erosion</li> </ul> </li> <li>• Vegetation               <ul style="list-style-type: none"> <li>o LD_01 Extent (proportion and area) of native vegetation (cross-reference to Biodiversity)</li> <li>o LD_03 Extent and proportion of deep-rooted perennial (woody) vegetation cover.</li> </ul> </li> <li>• Nutrients and sediments – sources and loads               <ul style="list-style-type: none"> <li>o IW_12 Catchment nitrogen and phosphorus load</li> <li>o IW_13 Catchment sediment load</li> </ul> </li> <li>• Sources of other pollutants               <ul style="list-style-type: none"> <li>o IW_14 Volume of sewage discharge to surface waters by treatment category (primary, secondary, tertiary)</li> <li>o IW_15 Volume of sewage discharged to land</li> <li>o IW_16 Total pesticide use</li> </ul> </li> </ul> |
| <b>Habitat scale influences</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| <ul style="list-style-type: none"> <li>• In-stream habitat – woody debris and sand slugs               <ul style="list-style-type: none"> <li>o IW_24 Extent of sedimentation (incl sand slugs)</li> <li>o IW_13 Catchment sediment load</li> <li>o IW_18 Exceedence of suspended solids water quality triggers</li> <li>o IW_25 Number and extent of re-snagging</li> <li>o IW_30 Macroinvertebrate condition</li> </ul> </li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |

### Commonwealth State of the Environment (2006)—inland waters

- Riparian vegetation
  - o IW\_26 Length of intact riparian zone >50-100 m wide
  - o BD\_16 The proportion and area of native vegetation remaining
  - o LD\_01 Extent (proportion and area) of native vegetation (cross-reference to Biodiversity)
  - o IW\_34 Wetland vegetation condition
  - o LD\_03 Extent and proportion of deep-rooted perennial (woody) vegetation cover
  - o LD\_17 Fragmentation of remnant vegetation. (cross reference to Biodiversity)
  - o IW\_30 Macroinvertebrate condition
- Wetlands
  - o IW\_27 Condition of significant wetlands
  - o IW\_34 Wetland vegetation condition
  - o IW\_33 Waterbirds – Abundance and distribution
  - o IW\_39 Wetland weeds
  - o IW\_48 Ramsar wetlands with implemented management plans
- Fish passage
  - o IW\_28 Number of effective fishways
  - o IW\_11 Number of licences dams, weirs, regulators and levees

### Water Quality (for surface and groundwater)

- Sediment and turbidity
  - o IW\_17 Exceedence of turbidity water quality triggers
  - o IW\_18 Exceedence of suspended solids water quality triggers
- Nutrients
  - o IW\_19 Exceedence of total nitrogen and phosphorus water quality triggers
- Salinity
  - o IW\_20 Exceedence of salinity water quality triggers
- Other pollutants
  - o IW\_21 Exceedence of pH water quality triggers
  - o IW\_22 Exceedence of biological and chemical water quality triggers
- Thermal pollution
  - o IW\_23 Mapping of water temperature depression due to dam releases

continued on next page

# 3 Literature Search

Table 15 continued from previous page

| Commonwealth State of the Environment (2006)—inland waters                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Response of Biota</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| <ul style="list-style-type: none"> <li>• Bacteria and algae               <ul style="list-style-type: none"> <li>o IW_29 Blue Green Algae</li> </ul> </li> <li>• Macroinvertebrates               <ul style="list-style-type: none"> <li>o IW_30 Macroinvertebrate condition</li> </ul> </li> <li>• Fish               <ul style="list-style-type: none"> <li>o IW_31 Fish – Abundance and Distribution</li> </ul> </li> <li>• Frogs               <ul style="list-style-type: none"> <li>o IW_32 Frogs – Abundance and distribution</li> </ul> </li> <li>• Waterbirds               <ul style="list-style-type: none"> <li>o IW_33 Waterbirds – Abundance and distribution</li> </ul> </li> <li>• Wetland and floodplain communities               <ul style="list-style-type: none"> <li>o IW_34 Wetland vegetation condition</li> </ul> </li> <li>• Exotic pests               <ul style="list-style-type: none"> <li>o IW_35 Total number of introduced aquatic pests (fish, amphibians, mammals, plants)</li> <li>o IW_36 Willow removal</li> <li>o IW_37 Carp removal and/or commercial catch</li> <li>o IW_38 Cane toad distribution</li> <li>o IW_39 Wetland weeds</li> </ul> </li> <li>• Stream metabolism               <ul style="list-style-type: none"> <li>o IW_40 Benthic metabolism case studies</li> </ul> </li> </ul> |
| <b>Human response – policy and management</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| <ul style="list-style-type: none"> <li>• New policy and management initiatives               <ul style="list-style-type: none"> <li>o IW_43 Implementation of National Water Initiative</li> </ul> </li> <li>• Management of surface and groundwaters               <ul style="list-style-type: none"> <li>o IW_44 Sustainable yield determination</li> <li>o IW_06 Average annual groundwater pressure</li> <li>o IW_05 Average annual groundwater depth</li> <li>o IW_08 Groundwater used for irrigation</li> <li>o IW_09 Groundwater used for urban/industrial</li> <li>o IW_46 Implementation of COAG principles</li> <li>o IW_45 Groundwater management plans that consider groundwater dependent ecosystems</li> <li>o IW_47 (reduction in) Number of licensed point sources to inland waters</li> <li>o IW_48 Ramsar wetlands with implemented management plans</li> <li>o IW_49 River/catchment plans with aquatic biodiversity targets and funded actions</li> </ul> </li> </ul>                                                                                                                                                                                                                                                                                                                                               |

#### Commonwealth State of the Environment (2006)—inland waters

- Environmental flows allocation and management
  - o IW\_46 Implementation of COAG principles
- Habitat management (including wetland management)
  - o IW\_47 (reduction in) Number of licensed point sources to inland waters
  - o IW\_48 Ramsar wetlands with implemented management plans
- Management of aquatic biota and biodiversity
  - o IW\_49 River/catchment plans with aquatic biodiversity targets and funded actions

#### Commonwealth State of the Environment (2006)—coasts and oceans

##### Condition of the Ocean

- Condition of marine biodiversity
  - o CO\_O1 Trends in key species
  - o CO\_O2 Condition of threatened species
  - o CO\_16 Status of Australian fisheries
  - o CO\_44 Marine Chlorophyll concentrations
- Other aspects of ocean condition
  - o CO\_03 Sea level
  - o CO\_04 Sea Surface temperature variability
  - o CO\_05 Changes in ocean currents
  - o CO\_45 Estuarine condition index
  - o CO\_46 Comparative water quality of coastal lakes and lagoons

##### Ocean contributions to Human Life

- Ecological services (air, water, climate)
- Food
  - o CO\_07 Australian fisheries production
  - o CO\_08 Aquaculture production
- Medicines and other potentially useful biological compounds
  - o CO\_09 Number of compounds at some stage of commercial development
- Non-living material (materials and energy fuels)
  - o CO\_10 Energy and dollar value of ocean-derived energy fuels
  - o CO\_47 Quantity and dollar value of selected other ocean-derived non-living materials
- Non-material values (heritage, recreation, aesthetic and spiritual)
  - o CO\_12 Value of and numbers participating in coasts and ocean-based eco-tourism and recreation
- Medium for transportation
  - o CO\_14 Number of Ship visits
  - o CO\_15 Number and tonnage of containers and bulk commodities imported and exported by sea

continued on next page

# 3 Literature Search

Table 15 continued from previous page

| Commonwealth State of the Environment (2006)—coasts and oceans                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Direct pressure of Human Settlements on Coasts and Oceans</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| <ul style="list-style-type: none"> <li>• Direct pressure of harvesting living materials (fishing)               <ul style="list-style-type: none"> <li>o CO_16 Status of Australian fisheries</li> <li>o CO_17 Historical change in trophic structure of commercial catches</li> <li>o CO_18 Historic change in trophic structure of recreational and Indigenous catches</li> <li>o CO_19 Illegal fishing: estimated tonnage taken; estimated number of illegal boats; estimated number of individuals of threatened species taken</li> <li>o CO_20 Proportion of seabed disturbed by shelf, slope and deep ocean</li> <li>o CO_21 Proportion by weight of bycatch</li> <li>o CO_22 Aquaculture: extent of habitat removed</li> <li>o CO_23 Aquaculture: volume of discharged sediments and nutrients</li> <li>o CO_24 Aquaculture: origin species and tonnage of stockfeed used</li> <li>o CO_25 Aquaculture: instances of disease and exotic species introduction from movement of live material</li> </ul> </li> <li>• Direct pressure of harvesting non-living materials               <ul style="list-style-type: none"> <li>o CO_26 Area disturbed/potentially disturbed by rigs, pipelines etc</li> <li>o CO_27 Number, frequency, extent and volume of spills/leaks from rigs, pipelines etc</li> <li>o CO_48 Area disturbed/potentially disturbed by seismic noise</li> </ul> </li> <li>• Pressure of shipping               <ul style="list-style-type: none"> <li>o CO_49 Number, frequency, extent and volume of spills, collisions, shipwreck and leaks from shipping</li> <li>o CO_50 Estimated number of collisions with marine animals</li> <li>o CO_51 Quantity of sewerage, garbage and ballast water dumped</li> <li>o CO_52 Area affected by channel dredging for shipping</li> </ul> </li> <li>• Pressure of coastal activities (other than shipping and fishing)               <ul style="list-style-type: none"> <li>o CO_28 Volume of discharges from settlements and inland water outflows (cross reference to Land)</li> <li>o CO_29 Coastal pollution: area of potential acid sulphate soils disturbed by development draining into coastal waters (cross reference to Land)</li> <li>o CO_53 Coastal pollution: potential disturbance of coastal and marine animals by visual and noise pollution from coastal activities</li> <li>o CO_30 Displacement and disturbance of ecosystems: length and area of coastal and estuarine foreshore occupied by human structures or otherwise altered for human purposes</li> </ul> </li> <li>• Similar or cumulative pressures arising from multiple causes (fishing, shipping, energy and mineral exploration/exploitation and coastal activities)               <ul style="list-style-type: none"> <li>o CO_31 Cumulative pollution: number and extent of harmful algal blooms</li> <li>o CO_32 Cumulative pollution: quantity of marine debris from all sources</li> </ul> </li> </ul> |

## Commonwealth State of the Environment (2006)—coasts and oceans

### Pressures and contributions between Atmosphere and Oceans

- Climate
  - o A\_01 Annual variations in the Southern Oscillation Index
  - o CO\_03 Sea level'
  - o CO\_05 Changes in ocean currents
- Ozone
  - o A\_13 Surface ultraviolet radiation in Australia and New Zealand – mean summer total ozone and estimated ultraviolet index
- Airborne Substances

### Pressures and Contributions between Inland Water and Oceans

- Condition of Interface Waters
  - o CO\_28 Volume of discharges from settlements and inland water outflows (cross reference to Land)
  - o CO\_03 Sea level
- Condition of Interface Species
  - o CO\_01 Trends in key species

### Pressures and Contributions between Land and Oceans

- General sub-issue
  - o CO\_03 Sea level
  - o CO\_05 Changes in ocean currents
- Land outflows to coastal waters
  - o CO\_28 Volume of discharges from settlements and inland water outflows (cross reference to Land)
  - o CO\_29 Coastal pollution: area of potential acid sulphate soils disturbed by development draining into coastal waters (cross reference to Land)
  - o Condition of interface species
  - o CO\_01 Trends in key species

### Oceans Response Indicators

- General responses
  - o CO\_33 Number of species legislatively protected by class and jurisdiction (cross reference to Biodiversity)
  - o CO\_54 Number/percentage of protected species with management plans in place
  - o CO\_55 Number percentage of protected species where management actions have been taken
  - o CO\_34 Number and extent of Marine Protected Areas (cross reference to Biodiversity)
  - o CO\_56 Number/percentage of Marine Protected Areas under management plans
- Responses to fishing pressures

continued on next page

# 3 Literature Search

Table 15 continued from previous page

| Commonwealth State of the Environment (2006)—coasts and oceans                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <ul style="list-style-type: none"> <li>o CO_35 Proportion of State and Commonwealth fisheries under management plans or EPBC assessment</li> <li>o CO_36 Changes in numbers of non-target species caught in bycatch since introduction of exclusion devices (cross reference to Biodiversity)</li> <li>o CO_37 Numbers and proportions of recreational fishers subject to restriction (eg size or bag limits)</li> <li>o CO_57 Extent of marine environment subject to prohibition or management of recreational fishing</li> <li>• Responses to shipping pressures               <ul style="list-style-type: none"> <li>o CO_38 Changes in volume of ballast water released since commencement of ballast water strategy</li> <li>o CO_39 Change in number of reports of exotic species introduction since commencement of marine pest strategy</li> <li>o CO_40 Changes in quantities of oil spilled since introduction of oil spill strategy</li> </ul> </li> <li>• Responses to exploration and extraction pressures</li> <li>• Responses to coastal pressures               <ul style="list-style-type: none"> <li>o CO_41 Changes in coastal area under any level of explicit environmental management</li> <li>o CO_42 Area or volume of coastal lagoons and lakes protected from discharges or where discharges are managed</li> <li>o CO_43 Number, area or volume of coastal lagoons and lakes with entrance protection plans</li> </ul> </li> </ul> |
| Queensland State of the Environment (2003)—Inland Waters                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| <p><b>Groundwater – subartesian water levels</b></p> <ul style="list-style-type: none"> <li>• Artesian and sub-artesian water extraction rates vs availability</li> <li>• Groundwater levels</li> <li>• Introduction of uncontrolled artesian bores</li> </ul> <p><b>Groundwater – artesian bore pressure</b></p> <ul style="list-style-type: none"> <li>• Number of uncontrolled artesian bores</li> <li>• Total length of bore drains</li> <li>• Trend in artesian bore pressure</li> <li>• Number of artesian bores capped</li> <li>• Groundwater efficiency measures – length of bore drains piped</li> </ul> <p><b>Groundwater quality</b></p> <ul style="list-style-type: none"> <li>• Land clearing – extent of deep-rooted vegetation cover by catchment</li> <li>• Rural and urban development</li> <li>• Stream regulation and land irrigation</li> <li>• Exceedances of groundwater quality guidelines</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |

### Queensland State of the Environment (2003)—Inland Waters

#### Surface water quantity

- Surface water extraction rates
- Surface water extraction vs availability
- Irrigation: water use by sector, area irrigated
- Mean annual flow, % of 'natural' / predevelopment
- Variability of flow (APDF or equivalent)
- Storage capacity (as % median annual runoff)
- Introduction of WRPs / ROPs (environmental flows objectives, number of plans, aerial coverage)
- Introduction of Land and Water Management Plans
- Regulation of overland flow
- Increase in wastewater reuse (where appropriate)

#### Surface water quality

- Discharges of pollutants into waterways from point sources
- Land practices, usage of chemical fertilisers and pesticides
- Land clearing – extent of deep-rooted vegetation cover by catchment
- Riparian zone condition
- Livestock access to streams
- River regulation, construction sites, sand and gravel extraction and mining
- Water abstraction
- Assessment of surface water quality parameters (salinity, pH, total N, total P, turbidity, pesticides) by catchment and in critical problem areas
- Assessment of secondary surface water quality parameters (dissolved oxygen, sediment N, P, toxicants, faecal contaminants)
- Incidences of algal blooms
- Extent and type of wastewater treatment – improved level of sewage and industrial wastewater treatment (e.g. from secondary to tertiary)
- Development of major water resource management initiatives
- Implementation of urban stormwater and effluent management plans by Local Authorities
- Extent of community participation (e.g. Landcare, Waterwatch, catchment mgt groups)

#### Aquatic ecosystems – riverine habitat

- Clearing of stream riparian vegetation, reduction of riparian widths
- Destruction of natural stream aquatic habitats
- Decline of river physical integrity (e.g. fragmentation, increasing lengths of river impoundment, channelisation, etc)
- Vegetated stream length
- Extent and condition of aquatic habitat
- Macroinvertebrate indices
- Estimated spread of exotic flora

continued on next page

# 3 Literature Search

Table 15 continued from previous page

## Queensland State of the Environment (2003)—Inland Waters

### Aquatic ecosystems – wetlands

- Reduction in wetland cover
- Extent, diversity and condition of wetlands
- Wetland protection measures and restoration rates

### Aquatic ecosystems – fish

- Barriers to movement of aquatic biota
- Estimated spread of exotic biota (flora and fauna)
- Commercial and recreational fishing
- Status of fish stocks
- Macroinvertebrate biodiversity (richness) indices
- Distribution of endangered and 'iconic' aquatic species
- Restoration of passage
- Implementation of pest, plant and animal strategies (e.g. Exotic Pest Fish strategy)
- Limits to harvest

## Queensland State of the Environment (2003)—The Coastal Zone

### Coastal resource use and development

- Changes in coastal use compared with 1999 where possible. Area of land in the coastal zone in the natural state (by habitat type – wetlands, mangroves, saltmarsh, melaleuca, intertidal flats, dune vegetation). Area of land in the coastal zone in other than natural state (by land use – urban, agricultural, plantation, public, private etc). Lineal extent of land developed (i.e. changed from natural) along the coastline.
- Total number and percentage of state's population living in the coastal zone
- Annual average population growth by local government area
- Annual cargo throughput for Queensland Ports
- Annual tonnage of petroleum products moved by sea (import and exports)
- Annual number of pollution incidents in Queensland's territorial waters and offshore reported to the Australian Maritime Safety Authority
- Number and areal extent of approved extractive activities (by type e.g. silica and mineral sands) for each coastal region (tidal and non-tidal)
- Visitor bed numbers in the coastal zone
- Number of visitor permits to coastal and marine parks (including the Great Barrier Reef Marine Park)
- Number of recreational (motor and sail) and commercial vessels registered in Queensland
- Total seafood catch (total catch and effort by species of commercial fish, crustacean and mollusc species)
- Recreational fish catch and effort
- Annual total bycatch by fishery (commercial)
- Area of seabed trawled and intensity of trawling
- Number of authorities to collect aquarium fish
- Number of permits to collect shells (and total volume)
- Areal extent of declared fish habitat areas

#### Queensland State of the Environment (2003)—The Coastal Zone

- Turtle, dugong and dolphin mortality through commercial fishing activity, shark nets and indigenous hunting
- Area of coast in each coastal region under aquaculture ponds/cage facilities
- Annual aquaculture production (by type)

#### Coastal water quality

- Bioaccumulated pollutants
- Algal blooms in estuarine and marine environments
- Coastal discharges (quantity of nitrogen, phosphorus, sediments and other contaminants discharged per catchment area for each coastal region)
- Marine pollution incidences
- Exceedences of marine and estuarine water quality guidelines
- Wastewater treatment – coastal waters. Discharge volume of primary, secondary and tertiary treated effluent (domestic and industrial sewage) into coastal waters
- Disturbance of acid sulfate soils

#### Coastal habitats and biodiversity

- Disturbance of marine habitat
- Estimated wild fish stocks
- Extent and diversity of estuarine, coastal and marine habitats (mangrove area, saltmarsh area, seagrass area (and changes since 1999), coral reef area, dune vegetation)
- Number and type of marine and terrestrial pest and displaced species identified as of concern in each coastal region
- Ship arrivals from foreign ports and ballast water discharged to Queensland waters

#### Coastal variability – physical processes

- Sea level (and wave variability)
- Sea surface temperature variability
- Storm surge height
- Number and intensity of cyclone events for each coastal region

continued on next page

# 3 Literature Search

The Great Barrier Reef Water Quality Protection Plan ('The Reef Plan') is aimed at addressing diffuse pollution from broadscale landuse. A number of strategies and actions have been identified that support the objectives and goal of the Plan i.e. 'Halting and reversing the decline in water quality entering the Reef within 10 years'. It builds upon existing participation and support of stakeholders in identifying and implementing solutions, and facilitates sustainable natural resource management and long-term security of industries reliant on the Reef and its catchment (State of Queensland and Commonwealth of Australia 2003).

## Queensland State agencies

In addition to the programs detailed above, NRW also undertakes regular state-wide freshwater riverine monitoring of water quality and macroinvertebrate assemblage to assess river health. The EPA undertakes water quality monitoring of the State's estuarine and marine waters using physical, chemical and biological indicators. NRW, in collaboration with the EPA, is currently developing a new monitoring program known as SEAP (Stream and Estuarine Assessment Program), which aims to assess the condition of aquatic ecosystems at the whole state scale and evaluate change in condition over time. This will be done in the context of hypotheses explaining how Queensland's aquatic ecosystems respond to particular human activities, and the biophysical changes to the aquatic environment resulting from the activities. Conceptual models will define these hypotheses.

## 3.3 Manuals and reviews

The most recent manual published in Australia on indicators and methodologies for wetlands is 'Recommended Methods for Monitoring Floodplains and Wetlands' (Baldwin et al. 2005). It details a consistent approach to selecting indicators and methods, and evaluating and reporting on changes to floodplains and wetlands. Whilst the indicators and methods are universally applicable to many wetland types, the brief for the project was limited to the types of wetlands and floodplains found in the Murray-Darling Basin (D. Baldwin pers. comm.). Pertinent information on monitoring and evaluation, setting objectives, defining conceptual models,

selecting indicators and methods, and evaluation and reporting is contained in this document and is applicable to any wetland program. The bulk of the text is given over to identifying indicators and methodologies (Table 16). Several appendices address monitoring programs throughout Australia, advantages and disadvantages of various taxa as tools for monitoring wetland condition, programs for specific interventions, and information on waterbird habitat preferences.

More specific information concerning wetland monitoring in Victoria was documented in a report entitled 'Options for the assessment and monitoring of wetland condition in Victoria' by Butcher (2003) in response to a Victorian Government mandate to establish a wetland assessment and monitoring program in that state. This document reviewed the national and international scientific literature on wetland condition and indicators, provided options for a statewide wetland condition monitoring program, and assessed the applicability, success or difficulties associated with the methods identified.

In 1998, van Dam et al. identified rapid assessment techniques for the early detection of pollutant impacts on wetland ecosystems, particularly in the wet-dry tropics of northern Australia. The paper describes the ideal attributes of early warning indicators and then evaluates the potential of existing assessment methods as early warning indicators of wetland degradation.

Victoria's Department of Sustainability and Environment has recently compiled a document as part of the Index of Wetland Condition project which details the different approaches to wetland studies throughout the world and at varying scales, the methods employed, and indicators used (DSE 2006). Appendix 3 in the document summarizes wetland assessment programs and is complementary to this literature search.

**Table 16. Indicator headings and indicators identified for the floodplains and wetlands of the Murray-Darling Basin (Baldwin et al. 2005).**

| Indicator Headings                | Indicators                                                                                                                                                                                                                                           |
|-----------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Groundwater                       | <ul style="list-style-type: none"> <li>• Groundwater level</li> <li>• Electrical conductivity</li> <li>• Reduced iron and manganese</li> <li>• Sulphate and sulphide</li> </ul>                                                                      |
| Soil and sediment                 | <ul style="list-style-type: none"> <li>• Soil moisture content</li> <li>• Soil electrical conductivity (salinity)</li> <li>• Soil water potential</li> <li>• Soil carbon</li> <li>• Presence of sulphidic and/or acid producing sediments</li> </ul> |
| Phytoplankton                     | <ul style="list-style-type: none"> <li>• Algal community structure</li> <li>• Chlorophyll a</li> </ul>                                                                                                                                               |
| Floodplain and wetland vegetation | <ul style="list-style-type: none"> <li>• Vegetation community structure</li> <li>• Vegetation condition</li> </ul>                                                                                                                                   |
| Macroinvertebrates                | <ul style="list-style-type: none"> <li>• Macroinvertebrate community structure</li> <li>• Macroinvertebrate diversity and abundance</li> </ul>                                                                                                       |
| Fish                              | <ul style="list-style-type: none"> <li>• Electrofishing</li> <li>• Bait traps</li> <li>• Seine nets</li> <li>• Fyke nets</li> </ul>                                                                                                                  |
| Frogs                             | <ul style="list-style-type: none"> <li>• Frog community structure</li> <li>• Frog diversity and abundance</li> </ul>                                                                                                                                 |
| Birds                             | <ul style="list-style-type: none"> <li>• Aerial survey</li> <li>• Area searches</li> <li>• Nest surveys</li> </ul>                                                                                                                                   |

### 3 Literature Search

Internationally, the USEPA has reviewed programs and methodologies extensively. Fennessy et al. (2004) identified rapid methods that are most suitable for assessing the ecological condition of lacustrine and palustrine wetlands. Despite the variety of purposes for which these methods or assessments were developed, there were many common features. More recently, the USEPA has been developing a series of modules (Methods for Evaluating Wetland Condition) accessible via the Internet, to assist states and tribes to build their capacity to conduct ecological assessments of wetland health.

A handbook for monitoring wetland condition in New Zealand describes a set of science-based indicators to monitor the condition of New Zealand estuarine and palustrine wetlands (Clarkson et al. 2004). It was designed for managers, landowners and community groups and focuses on the major threats and stress factors known to damage wetlands.

Guidelines for the rapid ecological assessment of biodiversity in inland water, coastal and marine waters were delivered to the Ramsar COP9 meeting in 2005 and recently published (CBD Secretariat/ Ramsar Convention Secretariat 2006). They focus on the assessment of biological diversity at the species and community level. Reference is also made to tools which will assist in the assessment of wetland ecosystems. A 'decision tree' to facilitate the selection of appropriate methods is presented and summary information on a range of appropriate and available methods suitable for each rapid assessment purpose is included, as is information on a range of different data analysis tools.

The European Water Framework Directive is an integrated river basin management program for Europe. It was designed in response to growing concern over the degraded state of water in Europe. River basin management plans are being developed across Europe and will undergo revision every six years. Ecological and chemical protection of surface and ground water are priorities and are assisted by a series of directives. The plan is a detailed account of how the objectives set for the river basin (ecological status, quantitative status, chemical status and protected area objectives) are to be reached within the timescale required. It will include the river basin's characteristics, a review of the impact of human activity on the status of waters in the basin, an estimation of the effect of existing legislation and the remaining "gap" to meeting these objectives; and a set of measures designed to fill the gap. Additionally, an economic analysis of water use within the river basin must be carried out (Water Framework Directive website, accessed 19.6.07).

# 4. Wetland Classification

Wetlands have traditionally been classified as a way of identifying similar traits which might allow them to be managed, utilised or investigated in a systematic manner. There are many variations, depending upon the type of wetland and the attributes that are used to classify. For instance, many States in Australia have developed classification systems for lacustrine and palustrine wetlands to complement their programs; Queensland has not formally done this. As the Programme has progressed, particularly through this Scoping Study, it has become apparent that a formal classification of wetlands is necessary to ensure that all wetland types are identified and characterised.

## 4.1 Wetland definition

The definition of wetlands, as used by the State agencies in the Queensland Wetlands Programme was derived at a series of workshops and discussions involving State government scientists and officers in scoping the Mapping, Classification and Inventory Database project (EPA 2005b). It was subsequently endorsed by the Queensland Wetlands Joint Government Taskforce (QWJGT) for use by the Queensland Wetlands Programme. It is based on an internationally accepted definition (Ramsar) and tailored to Queensland conditions and information. Wetlands in Queensland are defined as:

*Areas of permanent or periodic/intermittent inundation, with water that is static or flowing fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed 6 m. To be a wetland the area must have one or more of the following attributes:*

- *at least periodically the land supports plants or animals that are adapted to and dependent on living in wet conditions for at least part of their life cycle.*
- *the substratum is predominantly undrained soils that are saturated, flooded or ponded long enough to develop anaerobic conditions in the upper layers.*
- *the substratum is not soil and is saturated with water, or covered by water at some time.*

## 4.2 Wetland types and sub-types

The Directory of Important Wetlands of Australia (DIWA) (Environment Australia 2001) is the current principal document of wetland classification in Australia. It is based upon the Ramsar wetland classification for use at a national and international level. Both the Ramsar Convention and DIWA have adopted a classification of wetlands where, at the ecosystem level, the classification is that proposed by Cowardin et al. (1979) into Marine (coastal wetlands including rocky shore), Estuarine (including deltas, tidal marshes and mangrove swamps), Riverine (wetlands along rivers and streams), Lacustrine (wetlands associated with lakes) and Palustrine (marshes, swamps and bogs) wetlands. Reservoirs (including water storage areas, excavations, wastewater ponds, irrigation channels, rice fields, canals) and Subterranean (inland subterranean wetlands) are also identified as wetland types. This is the classification adopted by the Queensland Wetlands Programme.

At a lower, or landscape and local wetland level, the number of classification systems and wetland sub-types increases exponentially. The Ramsar Convention and DIWA have identified 42 wetland types under three major headings similar to the broad Cowardin-style categories and then upon their geographic location, climate variables, water sources, dominant vegetation, and other distinguishing characteristics (Appendix 2). Whilst Ramsar and DIWA classifications differ slightly in the wetland sub-types that are recognised, they essentially classify wetlands using the same criteria.

There are other classifications that are based on geomorphological, hydrological, vegetation and water quality features. In many classifications, the Cowardin system is used as a primary filter and the wetlands under investigation are then classified according to the previously mentioned landscape features. Table 17 provides a list of wetland classifications and summary of category types currently in use in Australia and overseas.

# 4 Wetland Classification

**Table 17. Wetland classification systems.**

| Classification                                                                       | Details                                                                                                                                                                                                            |
|--------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Ramsar                                                                               | 42 sub-types identified under three major headings: Marine and Coastal Zone Wetlands, Inland Wetlands, and Human-made Wetlands (Appendix 2)                                                                        |
| Directory of Important Wetlands                                                      | 42 sub-types identified under three major headings: Marine and Coastal Zone Wetlands, Inland Wetlands, and Human-made Wetlands (Appendix 2)                                                                        |
| Cowardin et al. (1979) (North America)                                               | Five wetland types: Marine, Estuarine, Riverine, Lacustrine, and Palustrine; 56 wetland classes. Modifiers: water regime, substrate, vegetation                                                                    |
| Hydrogeomorphic (HGM) (Brinson 1993) (North America)                                 | One wetland type: Palustrine<br>Modifiers: geomorphic setting, water source and transport, hydrodynamics                                                                                                           |
| New Zealand Framework (Johnson and Gerbeaux 2004)                                    | Nine wetland types: Marine, Estuarine, Riverine, Lacustrine, Palustrine, Inland salt, Plutonic (= Karst), Geothermal, and Nival (= Alpine)<br>Modifiers: water regime, vegetation structure, vegetation, substrate |
| Blackman (1992) (Queensland) (based on Cowardin)                                     | Five wetland types: Marine, Estuarine, Riverine, Lacustrine, and Palustrine<br>Modifiers: water regime, substrate, vegetation                                                                                      |
| Wetland International – Oceania (Queensland's south-western wetlands) (Jaensch 1999) | Three wetland types: Riverine, Lacustrine, Palustrine: 20 sub-types.<br>Modifiers: salinity (fresh and saline), dominant vegetation                                                                                |
| Kingsford and Porter 1999 (Paroo River, Qld)                                         | Seven wetland categories<br>Modifiers: vegetation, geomorphology, salinity, hydrology                                                                                                                              |
| Timms 1999 (Currawinya, Qld)                                                         | Five wetland categories<br>Modifiers: geomorphology, hydrology, water quality, water plants, invertebrates, birds                                                                                                  |
| Casanova 1999 (Paroo Rivers, Qld)                                                    | Six wetland categories<br>Modifiers: water regime, vegetation                                                                                                                                                      |
| Timms and Boulton (2001) (Paroo River, Qld)                                          | Five wetland types: Marine, Estuarine, Riverine, Lacustrine, and Palustrine<br>Modifiers: Based on aquatic fauna (driving variables: salinity, turbidity, water regime)                                            |
| Northern Territory (Duguid 2002)                                                     | 71 wetland categories under the headings: Basins (17 types), Flats (4 types), Channels (21 types), Springs (18 types), Subterranean (1 type), and Artificial (10 types)                                            |
| NSW (Green 1997)                                                                     | 14 wetland categories under the headings: Coastal, Tableland, Inland.<br>Modifiers: hydrology, vegetation                                                                                                          |
| WA (Hill et al. 1996)                                                                | 13 wetland categories<br>Modifiers: salinity, vegetation                                                                                                                                                           |
| Victorian Index of Wetland Condition (uses Corrick and Norman 1980)                  | Two wetland types: Palustrine, Lacustrine; 39 sub-categories.<br>Modifiers: vegetation, hydrology, salinity                                                                                                        |

### 4.3 Wetland Description Tool

The Wetland Indicators Workshop was a forum to develop indicators for Queensland lacustrine, palustrine and groundwater wetlands. Part of that process was to identify wetland types, develop conceptual models for them, and identify drivers, pressures and potential indicators (Maher et al. 2006). As the reporting process proceeded, a number of weaknesses were identified that would not satisfy the requirements of the Queensland Wetlands Programme. A major requirement of a contemporary classification system is that different wetland types be identified using desktop techniques such as remote sensing and data trawling, particularly for determining extent and distribution.

Based on work by a working group of QWP project managers, attributes have been identified addressing characteristics of wetlands at increasingly specific scales (continental, ecosystem, landscape, and local) (Table 18). Each category has specific layers to identify different features of wetlands that have traditionally been used in classification systems.

It is inevitable that some wetlands will not exactly fit the new description categories, therefore it is important to recognise that a degree of flexibility is required to place wetland types within the tool. The method should be designed to draw upon existing data, as well as have the ability to incorporate new data. All layers may also have limitations depending on their reliability and their relevance to the desired objectives. Layers are identified as either primary or secondary. The latter layers are those layers that are not essential but that may fine tune the wetland classification, or that are currently difficult to source.

This Tool was also presented to the NLWRA Wetland Indicators national workshop for consideration as a translation tool between each jurisdiction's preferred wetland classification system and DIWA wetland sub-types. Only the Continental and Ecosystem layers were accepted; the Landscape and Local layers were rejected. Reasons for the rejection included a lack of financial support, jurisdictional ability to support such a tool, and a concern that, in time, the Tool would usurp their own State classifications. The additional layers were included in the National Wetland Indicators Final Report as an option (Conrick et al. 2007).

# 4 Wetland Classification

**Table 18. Wetland Description Tool layers to assist in classifying wetlands in Queensland.**

| Resolution  | Tier    | Category                            | Attribute                              |
|-------------|---------|-------------------------------------|----------------------------------------|
| Continental | Primary | Climate                             | Equatorial                             |
|             |         |                                     | Tropical                               |
|             |         |                                     | Subtropical                            |
|             |         |                                     | Desert                                 |
|             |         |                                     | Grassland                              |
|             |         |                                     | Temperate                              |
| Ecosystem   | Primary | Ecological systems                  | Marine                                 |
|             |         |                                     | Estuarine                              |
|             |         |                                     | Riverine                               |
|             |         |                                     | Lacustrine                             |
|             |         |                                     | Palustrine                             |
|             |         |                                     | Subterranean                           |
|             |         |                                     | Nival                                  |
|             |         |                                     | Reservoir                              |
| Landscape   | Primary | Soils (permanently inundated areas) | Peat (organic)                         |
|             |         |                                     | Mineral                                |
|             |         |                                     | Rock (non-soil)                        |
|             | Primary | Geomorphology / Topography          | Floodplain                             |
|             |         |                                     | Non-floodplain (springs, soaks, karst) |
|             |         |                                     | Non-floodplain (depressional)          |

| Resolution | Tier      | Category                      | Attribute                                                                                                                                                                                                               |
|------------|-----------|-------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|            | Secondary | Substrate                     | Igneous<br>Metamorphic<br>Sedimentary-detrital<br>Sedimentary-pyroclastic<br>Sedimentary-chemical or organic<br>Unconsolidated<br>Examples of these are:<br>Dolerite (Ig)<br>Granite (Ig)<br>Limestone (Sedim-detrital) |
| Local      | Primary   | Dominant Vegetation Structure | Forested<br>Shrub<br>Sedge/grass/forb<br>No emergent vegetation                                                                                                                                                         |
|            | Primary   | Water Regime                  | Commonly wet<br>Periodic inundation                                                                                                                                                                                     |
|            | Primary   | Water Type                    | Saline<br>Freshwater, low pH<br>Freshwater, neutral/high pH                                                                                                                                                             |

# 4 Wetland Classification

## Climate

Climate describes the synthesis of weather observations over a long period of time. It can be classified into zones using criteria such as rainfall, temperature, humidity and vegetation. The Climate Classification of Australia from the Bureau of Meteorology website is recommended as the basemap for this layer (Figure 1).

## Ecological systems

These are the categories identified by Cowardin et al. (1979) and being adopted by Ramsar and DIWA (Environment Australia 2001).

## Soils

Wetland soils impact directly on other wetland characteristics e.g. water quality, fauna, vegetation, and can be a reflection of the physical processes occurring in the wetland e.g. water inflow, water chemistry, filtering of pollutants. The national soils layer is the Australian Soil Resource Information System ([www.asris.csiro.au](http://www.asris.csiro.au)) which carries broad scale to point scale information.

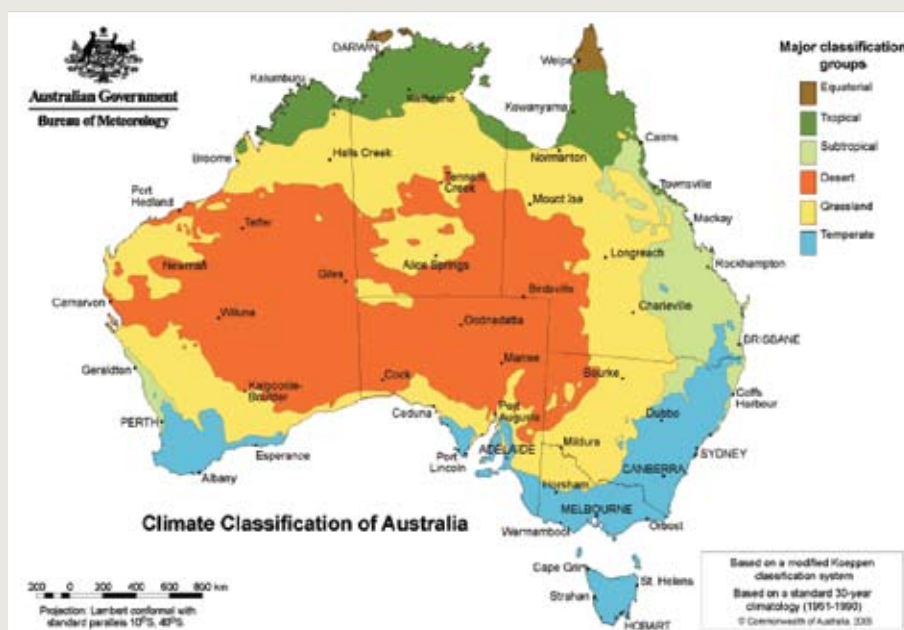
## Substrate

The substrate layer is the material lying below the soil layer that shows no pedological development. It may or may not be the parent rock of the wetland soil. This layer is proposed as a secondary layer that may be useful in describing wetlands but not essential. The proposed attributes are those described in McDonald et al. (1990). They summarize more than 70 categories of more recognisable rock types (e.g. igneous, dolerite, limestone).

## Geomorphology/Topography

This layer is derived from topographical maps and vegetation mapping layers to identify different landforms. Three relatively simple landforms are proposed based on floodplain, non-floodplain (springs, soaks and karst), and non-floodplain (depressional).

Figure 1. The Climate Classification of Australia map (Bureau of Meteorology).



## Dominant Vegetation Structure

Vegetation mapping layers from the Regional Ecosystems (RE) database are used to determine the dominant vegetation structure.

([http://www.epa.qld.gov.au/nature\\_conservation/biodiversity/regional\\_ecosystems/](http://www.epa.qld.gov.au/nature_conservation/biodiversity/regional_ecosystems/))

## Water Regime

Water regime stands alone as a component of wetlands that impacts upon all other facets of wetland existence. The presence of water, and its quality, quantity, and source, determines the salient features of a wetland. The information for this sub-category is derived from remote imagery (possibly satellite) of wetland extent over a range of wet and dry periods.

## Water Type

Wetland water chemistry is, in part, determined by the surrounding landscape and, in turn, dictates features of the wetland such as vegetation. This information can be used to determine the 'normal' water chemistry of a waterbody. Vegetation mapping layers are one source of remote sensing information that may be used to derive this sub-category, as well as other documented ground-based information.

## 4.4 Identification of Queensland wetland types

A latter phase of the Scoping Study project has been to use and test the Wetland Description Tool using wetland types identified through the literature (QWP Management Profiles (EPA 2006), Jaensch (1999); Timms (2001); Timms & Boulton (2001)) and on-going program development (AquaBAMM (P. Clayton pers. comm.), conceptual models developed in this project). The aim is to define a set of no more than 20 lacustrine and palustrine wetland types from which those types that are missing from the conceptual model set can be identified and developed.

A major focus of the project was to run an experts' workshop to scope and agree on key indicators for monitoring wetland extent and condition in Queensland. From the literature search, it became obvious that riverine and estuarine wetlands were the main focus of current research and monitoring efforts, and that there was a lack of information about lacustrine, palustrine and groundwater ecosystems in Queensland. It was therefore decided that the workshop would concentrate on the latter systems.

The workshop was attended by a broad cross-section of wetland workers from across Australia, with representatives from agencies, universities, NRM bodies, and NGOs. Under guidance from the participants, the first step was deemed to be the development of a framework for selecting indicators (Maher et al. 2006).

# 5 A Monitoring Framework

## 5.1 Indicator criteria

This was controlled by a suite of criteria developed from the National Monitoring and Evaluation Framework. The most important points were that indicators:

- are suitable for use within multiple Natural Resource Management processes;
- had the capacity to be grouped into a suite of indicators for use at a range of spatial scales from local to national and international;
- are cost-effective, affordable, consistent, and practical;
- are efficient in terms of time requirements;
- are SMART: smart, measurable, accessible, relevant, and timely; and
- have the capacity to be tested using existing technical capabilities.

## 5.2 Indicator considerations

Discussion of the issues surrounding indicator selection resulted in a suite of determining factors for identification of indicators (Table 19).

### Classification

Classification of inland non-riverine wetlands in Australia is a much debated topic and difficult to define due to the transient nature of wetland conditions. Most wetlands undergo varying phases of wetting and drying, subject to prevailing climate

**Table 19. Criteria for selecting indicators.**

| Consideration     | Criteria                                                                                                                                                                                                                                                                                                          |
|-------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| • Classification: | <ul style="list-style-type: none"><li>• wetlands types and sub-types</li></ul>                                                                                                                                                                                                                                    |
| • Purpose:        | <ul style="list-style-type: none"><li>• baseline condition and extent,</li><li>• cause and effect, or</li><li>• management responses</li></ul>                                                                                                                                                                    |
| • Spatial Scale:  | <ul style="list-style-type: none"><li>• individual,</li><li>• regional,</li><li>• state,</li><li>• national or</li><li>• international.</li></ul>                                                                                                                                                                 |
| • Time Scale:     | <ul style="list-style-type: none"><li>• short,</li><li>• medium, or</li><li>• long term.</li></ul>                                                                                                                                                                                                                |
| • Practicality:   | <ul style="list-style-type: none"><li>• skill level required<ul style="list-style-type: none"><li>o minimum,</li><li>o intermediate, or</li><li>o advanced, and</li></ul></li><li>• economic feasibility<ul style="list-style-type: none"><li>o low,</li><li>o medium, or</li><li>o high cost</li></ul></li></ul> |

conditions. Rather than being classified, they should be more correctly placed along a spectrum of wetland function at any one point in time. This may be the case in reality but, for the purposes of developing conceptual models and selecting indicators, it is functionally more rigorous to allocate a wetland to a sub-type description (see Section 4). This allows standardised conceptual models to be built, which may then be adapted for particular regions or conditions.

## Purpose

There is a need for clarity of purpose, or the end use, of an indicator in order to ensure that an appropriate indicator and methodology is defined. There can be several purposes for monitoring extent and condition of wetlands, including condition and trend, monitoring the success or otherwise of management actions and selecting an impact or pressure and monitoring its effect on the wetland. Different indicators may be necessary for each of these purposes. It is noted that not all indicators will work for all purposes.

## Spatial scale

The spatial scale of the monitoring must be defined and the indicators selected accordingly. The indicators that are useful at an individual or regional scale (e.g. fish assemblages) may be very different to those used at a State, national or international scale (e.g. remote sensing of riparian vegetation). It is noted that not all indicators will work at all scales, and that methodologies may differ for the same indicator at different scales or in different regions.

## Temporal scale

The purpose of monitoring wetlands is important in determining the time scale over which monitoring will occur. As wetlands also change over time, it is crucial to have an understanding of the cyclical nature of the wetlands under investigation. For these reasons it is often recommended that indicators measured over longer periods have a degree of permanency. Vegetation is often selected over aquatic elements as a suitable indicator. Selecting indicators that are not greatly impacted by time considerations will work better over varying time scales, enabling comparisons between datasets. Consideration should also be given to selecting indicators that are appropriate for the temporal scale and effort e.g. indicators that change regularly or widely are not appropriate if the sampling regime is irregular or infrequent.

## Practicality

Wetlands are potentially monitored by a range of organisations with varying skill levels from community groups through to advanced scientific groups. For an indicator to be truly universal, methodologies must be developed which consider the level of technical skills of the monitors. At community levels, basic testing and recording would be appropriate, whereas, at the advanced skill levels the monitoring would be more complex and an understanding of the processes and functions of wetlands would be essential.

Likewise, the cost of monitoring is a factor that also needs consideration. Often, the level of skill required will determine the cost, with more advanced methods incurring higher costs. There may also need to be tradeoffs where the higher costs are warranted, as lower cost resource condition indicators do not meet the needs of the purpose.

# 5 A Monitoring Framework

## 5.3 The framework

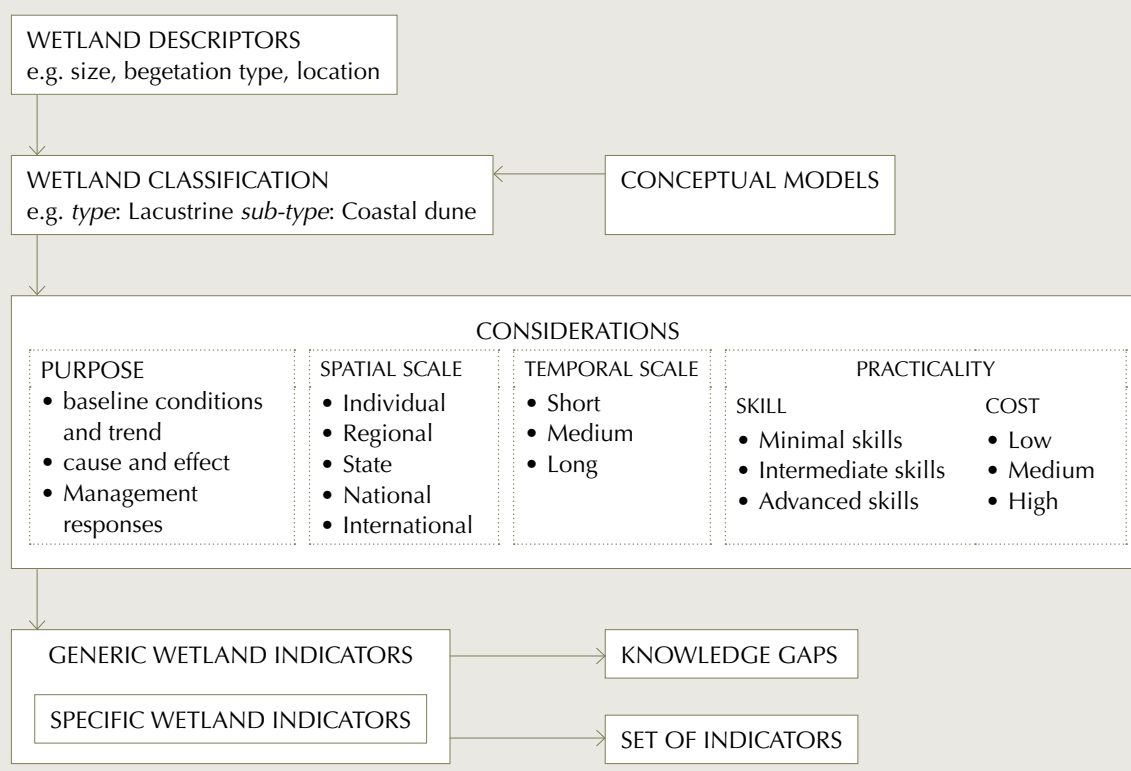
Identification of wetland descriptors and subsequent subtypes is the first step in the indicator identification process. This will direct the development of conceptual models and identification of key features of the wetland and the drivers, pressures, and impacts that are important to the functioning of the wetland. These, in turn, will determine the indicators that are sensitive to changes in the wetland condition. There is little point in monitoring something that will not change in response to an impact. It is expected that there will be a set of indicators that will be used across a set of wetland sub-types, and then there will be another set of indicators to address issues specific to individual wetland sub-types. As well as a set of indicators, knowledge gaps will also be identified. This framework is depicted diagrammatically in Figure 2.

## 5.4 Conceptual Models

The wetland sub-types that emerged through the workshop process were a mixture of palustrine and lacustrine wetlands identified by geographic location, vegetation, and geomorphology. Some were common occurrences in Queensland, whilst others were not. Time and capacity limited the subtypes that could be modelled, so some common subtypes were not addressed. The workshop conceptual models are presented and discussed in Section 9.

Consultation following the workshop suggested that there may be alternative ways of identifying wetland subtypes. This led to the development of the Wetland Description Tool (Section 4.3) as a classification system for Queensland.

**Figure 2. A framework for selecting wetland indicators (Maher et al. 2006).**



# 6 Application of the Framework in Queensland

# 6

Following the development of the framework by the workshop participants, the project team held discussions with other teams to discuss and find synergies between the Wetland Indicators Framework and the methods being used or proposed on other wetland programs.

## 6.1 Stream and Estuarine Assessment Program

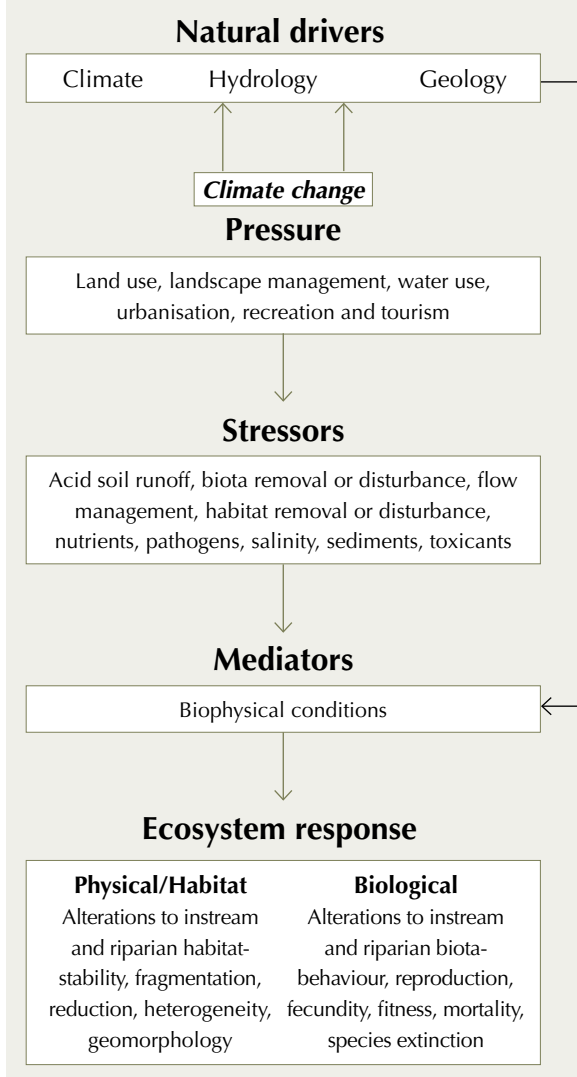
The Stream and Estuarine Assessment Program (SEAP) is a whole-of-government development driven by the Department of Natural Resources & Water and the Environmental Protection Agency which will eventually replace the current state-wide water quality monitoring programs. The recent review of roles and responsibilities of State Government agencies has reinforced the purpose and design of SEAP (Keliher 2007). It is a hypothesis-based program where conceptual models will be developed to explain how Queensland's aquatic ecosystems respond to particular human activities, and the biophysical changes to the aquatic environment resulting from the activities.

### Freshwater

The freshwater component of the SEAP is based upon a 'Pressure-Stressor-Response' (PSR) framework (Figure 3). Landscape elements that govern natural ecosystem function have been termed *natural drivers*. These interact to produce the variable biophysical conditions to which individual species, and hence ecosystems, are adapted. Human activities have been termed *pressures*. Pressures modify the biophysical conditions experienced by ecosystems and their constituents either indirectly, by modifying the drivers themselves (as is the case with climate change), or, more typically, by interacting with the influence of the drivers to directly modify the biophysical conditions within the ecosystem. The biophysical condition attributes that are modified by pressures have been termed *stressors* because they elicit ecosystem responses. Ecosystem condition for SEAP will be defined using a referential approach which provides the framework for the development of conceptual models. These models will describe the ecosystems as if they were unimpacted by human activity (Marshall et al. 2006b).

Queensland is divided into nine biogeographic provinces based upon the natural structural patterns expressed by one ecosystem constituent (aquatic macroinvertebrates) and then confirmed by another (fish) (Marshall et al. 2006c). Conceptual models of natural ecosystem function, which underpin the development of the PSR models, are being developed for each of Queensland's freshwater biogeographic provinces. The models are developed based on relevant literature and data, as well as expert

**Figure 3. Pressure-Stressor-Response (PSR) framework illustrating how human activities modify the prevailing biophysical conditions generated by natural drivers to elicit ecosystem responses (Marshall et al. 2006b).**



## 6 Application of the Framework in Queensland

knowledge and experience. Using the conceptual models and the PSR models, a list of prioritised stressors will be ascertained and the indicators appropriate to that particular province selected.

In essence, this framework aligns with the Wetland Indicator Selection Framework proposed by this project.

## Estuarine

The estuarine component of SEAP has a similar framework to the freshwater component, and is aligned to the NLWRA drive to identify appropriate indicators for the Estuarine, coastal and marine habitat integrity Matter for Target. It is driven by the Water Quality Management Framework developed by the EPA (Figure 4). This framework has been developed to underpin all of their ecological programs e.g. AquaBAMM, Ecological Value Assessments, State of the Environment reporting, NLWRA indicator trials. It aligns with the wetland indicators framework.

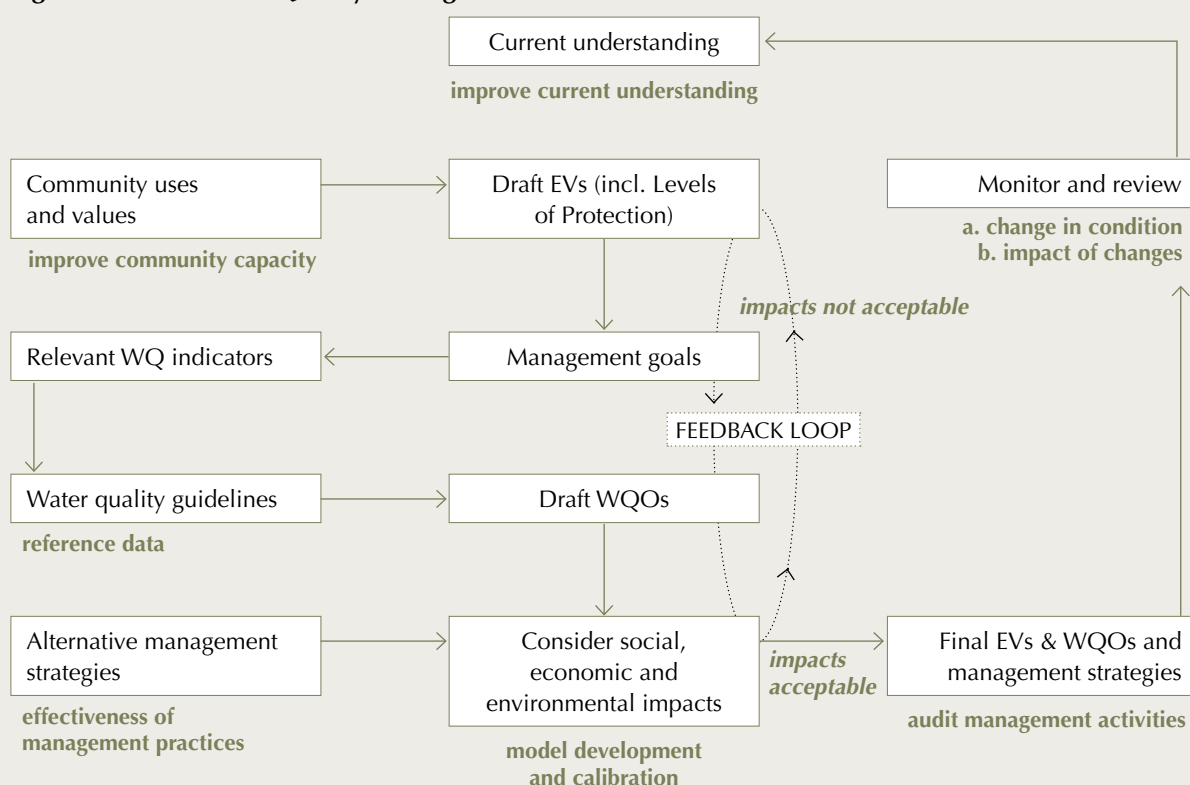
## 6.2 Ecosystem Health Monitoring Program

The EHMP program was developed in response to the South-east Queensland Regional Water Quality Management Strategy, which in itself was initiated by the recognition that the south-east corner of the State was under the threat of pressures by an ever-increasing population and the accompanying land use intensification.

It has six stages, three of which have been completed. Stage 1 was a scoping study, Stage 2 the development of the estuarine and marine monitoring program, and Stage 3 the development of the freshwater monitoring program (Abel et al. 2005).

The estuarine/marine monitoring program was built upon a conceptual model that integrates the current understanding of Moreton Bay and its associated waterways with community-driven environmental values. The model focused on assessing the responses of the ecosystem to natural and human pressures.

**Figure 4. EPA's Water Quality Management Framework.**



The freshwater monitoring program was developed by a study team which used a six-step process to identify and test the most appropriate indicators for assessing the health of waterways in South-east Queensland:

- A list of potential indicators addressing physical, chemical and biological attributes of river health was drawn up by the study team.
- Conceptual models to show the important attributes of river health and the impact by disturbances were developed.
- Streams in the region were classified to ensure that comparisons were made between similar types of streams.
- Pilot studies were undertaken to assess the usefulness of indicators.
- A major field trial was undertaken and the results assessed against a known diffuse land-use disturbance gradient. Indicators with strong relationships were recommended for the monitoring program.
- Five indicators, covering a range of processes, were used in the monitoring program.

The Wetland Indicators Framework aligns with both the estuarine/marine and the freshwater EHMP indicator selection.

## 6.3 eWater

eWater CRC is a cooperative venture, formed under the Australian Government's CRC Programme, and set up by Australia's water resource management and research sector. It currently has 45 industry partners including state governments, Federal government, universities and consultant groups. Its core business is building water management tools for partners and bringing those tools to Australian and international markets.

One of the many tools being proposed by eWater is the Integrated Monitoring and Assessment System (IMAS). This tool will assist the user to select physical, chemical and biological indicators for monitoring and assessment programs. As such it will support both new and existing monitoring and assessment programs. It will facilitate the development of well targeted monitoring programs, coupled to key performance indicators for environmental

management. This tool, although yet to be produced, appears to align with the Wetland Indicators Framework.

## 6.4 Lake Eyre Basin

In recent years much work has been done in the Lake Eyre Basin in preparation for sustained monitoring. Major projects include the joint South Australian and Queensland Aridflo project to develop an interactive predictive model of hydrology-biology relationships for Australian arid zone rivers, and the Lake Eyre Basin Rivers Assessment Methodology Development Project by Griffith University in conjunction with the Queensland Government for Land and Water Australia. Both these projects were developed with the knowledge that Australia's arid zone rivers are very different in their biology, hydrology and geomorphology compared to other Australian rivers, and it is essential that river management in this region is based on local information rather than extrapolation from other, wetter rivers.

Following on from these initial projects, the Lake Eyre Basin Assessment commenced as part of the Lake Eyre Basin Agreement between the Australian Government and the governments of Queensland, South Australia and the Northern Territory.

All these projects have developed conceptual understandings of the arid zone, and proposed multiple indicators for assessing river health. They all align with the principles of the Wetland Indicators Framework.

## 6.5 Sustainable Rivers Audit

The SRA was developed in a pilot program that utilised a conceptual model of river ecosystem function which states that *impacts can occur at the landscape, river reach or site scale, impacting on biota and their ecology at all scales* (MDBC 2004). Considerations such as biological and physical elements, structural and functional indicators and 'drivers as well as 'outcomes' were used to select appropriate indicators. Whilst the initial indicators were developed for instream habitats, indicators under development are for both instream and

# 6 Application of the Framework in Queensland

wetland habitats. The Audit will detect large scale change providing a standard framework across the Basin for comparing information. It aligns with the Wetland Indicators Framework.

## 6.6 Marine and Tropical Sciences Research Facility

The Marine and Tropical Sciences Research Facility is supporting many projects to research the key environmental challenges facing the Great Barrier Reef and its catchments, tropical rainforests, including the Wet Tropics World Heritage Area, and the Torres Strait. Two projects under Programme 7, Halting and reversing the decline of water quality, are investigating indicators and thresholds of concern in freshwater systems, and marine and estuarine systems. They are identifying and testing indicators in a conceptual model framework, and developing strategies for designing monitoring and assessment programs for the Wet Tropics region.

The Framework will bring together a number of related elements of riverine and wetland condition and derive indices that can be scaled and compared. It will detail how an assessment will be made ('how to'), but it will not be prescriptive on what is monitored (the indicators), although recommended methods will be provided. It will remain the prerogative of the jurisdiction to select indicators that are considered to be the most appropriate for the wetland or river reach being monitored. The ecological basis of condition indicator selection will be derived from conceptual models that identify key wetland ecological and physical drivers and pressures. Individual wetlands must be understood in terms of their physical, biological and chemical processes, and indicators should be selected to reflect the changes that may occur to a wetland under different impacts. In addition, assessments will be made against a referential condition. This Framework aligns strongly with the Wetland Indicators Framework.

## 6.7 Framework for the Assessment of River and Wetland Health

The National Water Commission is charged with implementing the National Water Initiative (NWI), a comprehensive strategy to improve water management across the country. Part of the NWI is to address environmental water provisions (water availability, water use, and river health), ensuring that water degradation can be detected and causes addressed. The Framework for the Assessment of River and Wetland Health is a component of the Australian Water Resources 2005 project. It is developing an approach that can be used by all Australian states and territories to provide assessments of river and wetland health that can be reported at a national scale from comparable state/territory-based assessments (Norris et al. 2007).

# 7 Riverine Wetlands

Riverine wetlands are those wetlands contained within a channel, that are not dominated by vegetation, and with water containing less than 0.5% ocean-derived salts. A channel is 'an open conduit either naturally or artificially created which periodically or continuously contains moving water, or which forms a connecting link between two bodies of standing water' (Langbein and Iseri 1960, cited in Cowardin et al. 1979).

## 7.1 Natural Resource Management Resource Condition Indicators

The current riverine NRM resource condition indicators are listed under the Inland Aquatic Ecosystems Integrity Matter for Target (River Condition) (Table 20). These indicators are currently undergoing review by the NLWRA as part of a system-wide review in preparation for the second Audit. Whilst many other Matters for Target have finished the review process, the riverine indicators were delayed until the development of the NWC Framework for the Assessment of River and Wetland Health (FARWH) was completed. This process is commencing in mid-2007. If the same process to the wetland indicators review is followed, it is expected that the indicators selected will align with the NWC FARWH themes.

## 7.2 Stream and Estuarine Assessment Program

As outlined earlier in this document (Section 6.1), the Stream and Estuarine Assessment Program (SEAP) is currently being developed by two State agencies (Natural Resources & Water (NRW) and Environmental Protection Agency (EPA)). It will eventually replace the current state-wide water quality monitoring programs run by those agencies. It is a hypothesis-based program where conceptual models will be developed to explain how Queensland's aquatic ecosystems respond to particular human activities, and the biophysical changes to the aquatic environment resulting from the activities. NRW is developing the freshwater component of the program and EPA the estuarine.

The freshwater component of the SEAP is based upon a 'Pressure-Stressor-Response' (PSR) framework (Figure 3 (Section 6.1)). Landscape elements that govern natural ecosystem function have been termed *natural drivers* which interact to produce the variable biophysical conditions to which individual species, and hence ecosystems, are adapted (e.g. climate). *Pressures* are human activities that modify the biophysical conditions experienced by ecosystems and their constituents either indirectly, by modifying the drivers themselves (e.g. climate change) or, more typically, by interacting with the influence of the drivers to directly modify the biophysical conditions within the ecosystem. The biophysical condition attributes that are modified by pressures have been

**Table 20. Riverine NRM resource condition indicators.**

|                                                          |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|----------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| River Condition<br><br>(Indicator Status:<br>For Advice) | <p>For regionally significant reach based issues that is the subject of targets in regional plans, the indicators are:</p> <ul style="list-style-type: none"><li>• Benthic macroinvertebrate community assemblages (Indicator Status: For Advice)</li><li>• Fish community Assemblages (Indicator Status: For Advice)</li><li>• Benthic diatom community assemblages (Indicator Status: For Advice)</li><li>• Riparian vegetation community assemblages (Indicator Status: For Advice)</li><li>• Riverine physical structure and in-stream habitat (Indicator Status: For Advice)</li><li>• Water quality (Indicator Status: For Advice)</li><li>• Hydrology (Indicator Status: For Advice)</li></ul> <p>If all or most of these indicators are measured, it may be possible to use monitoring data to develop an index of river condition</p> |
|----------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

# 7 Riverine Wetlands

termed *stressors* because they elicit ecosystem *responses*. Ecosystem condition for SEAP will be defined using a referential approach which provides the framework for the development of conceptual models. These models will describe the ecosystems as if they were unimpacted by human activity (Marshall et al. 2006b).

Queensland is divided into nine biogeographic provinces based upon the natural structural patterns expressed by one ecosystem constituent (aquatic macroinvertebrates) and then confirmed by another (fish) (Marshall et al. 2006c). Conceptual models of natural ecosystem function, which underpin the development of the PSR models, will be developed for each of Queensland's freshwater biogeographic provinces based on relevant literature and data, expert knowledge, and experience.

Pressures relevant to Queensland were identified from Regional NRM Plans. Using conceptual models and the PSR model, and utilising a risk assessment approach, a list of potential prioritised stressors will be determined and the indicators appropriate to that particular province selected. Factors that must also be considered are the feasibility of implementation, the amount of variability in the response that might be expected as well as knowing the trajectory of change (i.e. what the condition might be given that there had been no impact), and enough of an understanding of the indicator to enable accurate interpretation. As well as representing either a pressure, stressor or response, indicators can also be sensitive (will an indicator be precise enough to have confidence that it will identify the cause of an effect), general (can represent several different vectors) or early warning (provides an indication of change before serious environmental harm occurs).

Common stressors identified for Queensland are:

- Acid soil runoff
- Biota removal or disturbance
- Flow Management
- Habitat removal or disturbance – instream  
Habitat removal or disturbance – riparian
- Habitat fragmentation – instream
- Habitat fragmentation – riparian
- Thermal alteration
- Nutrients
- Organic matter
- Pathogens
- Pest species
- Salinity
- Sediments
- Toxicants

To date, only the Central Province (Fitzroy and Burdekin Basins) model has been developed and potential indicators identified. The stressors identified above were prioritised, and the capacity to monitor them was assessed. Pressure, stressor and response indicators and measures for Central Province are in Table 21. Indicators for other provinces will not be determined until the province is modelled.

It is expected that the SEAP program will be instigated in 2008 to replace the current state-wide river health monitoring program.

**Table 21. SEAP Indicators and measures identified for collection in the Central province of Queensland.**

| Stressor Model                               | Ecosystem Indicators                                                                                                                                                                                                      | Stressor Indicators                                                                                                                                                                                                                                              | Pressure Indicators                                                                                                                                                                                          |
|----------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1. Suspended solids                          | <ul style="list-style-type: none"> <li>Fish condition (decrease in fish food by increased suspended solids)</li> </ul>                                                                                                    | <ul style="list-style-type: none"> <li>Index of stream productivity potential (represents food availability to consumers)</li> </ul>                                                                                                                             | <ul style="list-style-type: none"> <li>Catchment erosion modelling</li> <li>Land use (GIS)</li> </ul>                                                                                                        |
| 2. Habitat removal or disturbance – riparian | <ul style="list-style-type: none"> <li>Bank stability</li> <li>Bed stability</li> <li>Presence and extent of different structural types of weeds</li> <li>Instream debris – wood and leaves</li> </ul>                    | <ul style="list-style-type: none"> <li>Riparian extent, connectivity</li> <li>Riparian habitat element measures: <ul style="list-style-type: none"> <li>structural vegetation types and cover</li> <li>woody debris</li> <li>bare patches</li> </ul> </li> </ul> | <ul style="list-style-type: none"> <li>Riparian/catchment land use</li> <li>Rate of removal</li> </ul>                                                                                                       |
| 3. Flow management – Vno flow spells         | <ul style="list-style-type: none"> <li>Tba</li> </ul>                                                                                                                                                                     | <ul style="list-style-type: none"> <li>IQQM flow change from natural</li> <li>No flow spells</li> </ul>                                                                                                                                                          | <ul style="list-style-type: none"> <li>Number of water abstractions/licences</li> </ul>                                                                                                                      |
| 4. Pest species – riparian                   | <ul style="list-style-type: none"> <li>Change to riparian vegetation community structure and cover</li> <li>Density of edible understorey plants (grazing pressures)</li> <li>Bank stability (cows/ wild pigs)</li> </ul> | <ul style="list-style-type: none"> <li>Direct measure of riparian weed structure and cover</li> <li>Cattle stocking density</li> <li>Pugging – footprints per length</li> <li>Watering access point along stream</li> </ul>                                      | <ul style="list-style-type: none"> <li>Extent of pest species</li> </ul>                                                                                                                                     |
| 5. Habitat removal or disturbance – instream | <ul style="list-style-type: none"> <li>Macroinvertebrate richness</li> </ul>                                                                                                                                              | <ul style="list-style-type: none"> <li>Substrate heterogeneity</li> </ul>                                                                                                                                                                                        | <ul style="list-style-type: none"> <li>Land use</li> <li>Riparian width</li> <li>Modelled catchment loads</li> </ul>                                                                                         |
| 6. Sediment deposits                         | <ul style="list-style-type: none"> <li>Changes in macroinvertebrate communities, substrate preference groups</li> </ul>                                                                                                   | <ul style="list-style-type: none"> <li>Rate of deposition</li> </ul>                                                                                                                                                                                             | <ul style="list-style-type: none"> <li>Modelling of catchment erosion</li> <li>Land use (GIS)</li> <li>Bare areas (GIS)</li> <li>Width and fragmentation of riparian zone</li> <li>Bank stability</li> </ul> |

# 7 Riverine Wetlands

## 7.3 Sustainable Rivers Audit

The Sustainable Rivers Audit (SRA) is a monitoring and assessment program for the Murray-Darling Basin, involving the participation of six governments (Australian, Queensland, New South Wales, Victoria, South Australia and Australian Capital Territory) and a community advisory group. It uses indicators to assess the current ecological condition of the Murray-Darling Basin river valleys (MDBC 2004). Three indicator themes are currently being monitored (fish, macroinvertebrates and hydrology) and others are under development (physical form, vegetation and floodplain). The current indicators target instream habitats; the vegetation and physical form indicators under development will encompass wetlands on the floodplain as well as instream habitats. The floodplain components of these themes will also be included in the floodplain theme, which is expected to consider many other components. Current and proposed indicators are in Table 22. This monitoring, both current and proposed, will provide information to assist in setting targets and developing strategies to improve the management of rivers.

## 7.4 Lake Eyre Basin Rivers Assessment

Under the Lake Eyre Basin (LEB) Agreement, the Lake Eyre Basin Ministerial Forum must review the condition of all the watercourses and catchment in the LEB Agreement Area. The LEB Rivers Assessment is reviewing the status of the Basin, identifying gaps in information, and developing a program to improve understanding of arid rivers and assist in monitoring design and implementation. (LEB website, accessed 29.5.07)

The Assessment Methodology Development Project developed a list of proposed indicators to assess the health of watercourses and catchments in the LEB. This list was later refined at a workshop attended by Government representatives, scientists, and regional representatives (Table 23). Outcomes of the report and workshop included:

- Three regions are recognised in the Basin: headwaters, channels and waterholes, and terminating wetlands. Indicators are allocated against one, two or all regions depending on their ability to assess changes in condition in those parts of the Basin.
- Four major themes of the Basin were identified: flood and river flows, catchment condition and physical form, riparian areas and floodplains, and waterholes and wetlands.

**Table 22. Themes, indicators and measures currently in use and being developed for the Sustainable Rivers Audit.**

| Theme Index    | Indicator        | Measure                                                                                                                                                                                                                                                                                  |
|----------------|------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Fish (channel) | Expected species | <ul style="list-style-type: none"><li>• Observed to expected (OE)</li><li>• Observed to predicted ratio (OP)</li><li>• Total species richness</li></ul>                                                                                                                                  |
|                | Nativeness       | <ul style="list-style-type: none"><li>• Proportion of native biomass</li><li>• Proportion of abundance</li><li>• Proportion of species</li></ul>                                                                                                                                         |
|                | Diagnostic       | <ul style="list-style-type: none"><li>• Pelagic species richness</li><li>• Benthic species richness</li><li>• Proportion macrocarnivores</li><li>• Proportion megacarnivores</li><li>• Total Abundance</li><li>• Fish with abnormalities</li><li>• Intolerant species richness</li></ul> |

| Theme Index                                                                                                              | Indicator                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | Measure                                                                                                                                                              |
|--------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Macroinvertebrates (channel)                                                                                             |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | <ul style="list-style-type: none"> <li>Richness biodiversity</li> <li>SIGNAL Score</li> <li>AUSRIVAS OE</li> </ul>                                                   |
| Hydrology<br>(channel)<br><br>(the indicators for this theme are those recommended from the Hydrology Pilot SRA Program) | High Flow                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | <ul style="list-style-type: none"> <li>1:2 year ARI Flood event number</li> <li>1:5 year ARI Flood event number</li> <li>1:10 year ARI Flood event number</li> </ul> |
|                                                                                                                          | Low and Zero Flow                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | <ul style="list-style-type: none"> <li>Low flow event number</li> <li>Low flow event duration</li> <li>Zero flow Days Difference</li> </ul>                          |
|                                                                                                                          | Variability                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | <ul style="list-style-type: none"> <li>Seasonal amplitude</li> <li>Yearly variation</li> </ul>                                                                       |
|                                                                                                                          | Seasonality                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | <ul style="list-style-type: none"> <li>Seasonal Period Index (frequency distribution)</li> </ul>                                                                     |
|                                                                                                                          | Flow volume                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | <ul style="list-style-type: none"> <li>Median Annual Flow</li> <li>Mean Annual Flow</li> <li>Amended APFD</li> </ul>                                                 |
| Physical Form<br>(channel and floodplain)                                                                                | This index is under development                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                                                                                                                                                                      |
| Vegetation<br>(channel and floodplain)                                                                                   | <p>This index is under development. Suggested indicators include:</p> <ul style="list-style-type: none"> <li>Structural <ul style="list-style-type: none"> <li>Spatial extent of vegetation types</li> <li>Spatial arrangement of vegetation types</li> <li>Structure <ul style="list-style-type: none"> <li>canopy height</li> <li>number of strata</li> <li>cover density</li> </ul> </li> <li>Nativeness</li> </ul> </li> <li>Functional/process <ul style="list-style-type: none"> <li>Modification of microclimate</li> <li>Recruitment and regeneration</li> <li>Physiological status</li> <li>Nutrient flux</li> <li>Sediment flux</li> <li>Water flux</li> <li>Provision of habitat</li> </ul> </li> </ul> |                                                                                                                                                                      |
| Floodplain                                                                                                               | This index is under development                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                                                                                                                                                                      |

# 7 Riverine Wetlands

**Table 23. Suggested themes, indicators and measures for detecting change in condition of different regions of Lake Eyre Basin.**

| Theme and Attribute                                 | Indicator                             | Measure                                                                                                                                                                                                                                              |
|-----------------------------------------------------|---------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Flow and Flood</b>                               |                                       |                                                                                                                                                                                                                                                      |
| Water use                                           | Volume of water held in storage       | <ul style="list-style-type: none"> <li>Upstream water licensing information</li> <li>Upstream area (volume) of water stored, from satellite imagery</li> </ul>                                                                                       |
|                                                     | Percent of flow diverted              | <ul style="list-style-type: none"> <li>Water licensing information</li> <li>Area (volume) of water diverted, from satellite imagery</li> </ul>                                                                                                       |
| Hydrological variability                            | Flow variability                      | <ul style="list-style-type: none"> <li>Long-term variability (and changes in variability) in amplitude, frequency and duration of floods</li> <li>Long-term changes in variability of multi-annual flows</li> <li>Predictability analyses</li> </ul> |
| Waterhole depth                                     | Depth                                 | <ul style="list-style-type: none"> <li>Depth loggers at waterhole</li> </ul>                                                                                                                                                                         |
| Flood extent                                        | Flood extent                          | <ul style="list-style-type: none"> <li>Mapping flood extent with satellite imagery</li> </ul>                                                                                                                                                        |
| Alluvial groundwater                                | Depth to alluvial groundwater         | <ul style="list-style-type: none"> <li>Site specific monitoring</li> </ul>                                                                                                                                                                           |
| <b>Catchment and Physical Form</b>                  |                                       |                                                                                                                                                                                                                                                      |
| Channel system integrity                            | Channel system integrity              | <ul style="list-style-type: none"> <li>Floodplain geomorphic complexity – remote sensing</li> <li>Channel complexity – remote sensing (aerial photography)</li> <li>Within waterhole complexity</li> </ul>                                           |
| Erosion potential and land use and landscape change | Erosion potential and land use change | <ul style="list-style-type: none"> <li>Landscape function analysis (per veg cover change including salinisation)</li> </ul>                                                                                                                          |
| Floodplain salinisation                             | Salinity scalds                       | <ul style="list-style-type: none"> <li>Area of scalds from remote sensing</li> </ul>                                                                                                                                                                 |
| <b>Riparian and Floodplain</b>                      |                                       |                                                                                                                                                                                                                                                      |
| Riparian and floodplain biodiversity                | Vegetation biodiversity               | <ul style="list-style-type: none"> <li>Riparian &amp; floodplain vegetation taxa richness</li> <li>Riparian &amp; floodplain vegetation functional diversity</li> </ul>                                                                              |
|                                                     | Bird biodiversity                     | <ul style="list-style-type: none"> <li>Riparian (adapted Bryce, Kingston) &amp; Waterbird (Kingsford) diversity</li> </ul>                                                                                                                           |
| Riparian vegetation condition                       | Riparian composition & extent         | <ul style="list-style-type: none"> <li>Riparian cover index</li> <li>Riparian SLATS</li> </ul>                                                                                                                                                       |
|                                                     | Riparian recruitment & regeneration   | <ul style="list-style-type: none"> <li>Riparian regeneration index</li> </ul>                                                                                                                                                                        |

| Theme and Attribute                          | Indicator                                               | Measure                                                                                                                                                                                   |
|----------------------------------------------|---------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                              | Riparian percent exotics                                | <ul style="list-style-type: none"> <li>Riparian NATIVES index</li> </ul>                                                                                                                  |
| Floodplain <sup>1</sup> vegetation condition | Floodplain composition & extent                         | <ul style="list-style-type: none"> <li>Floodplain cover index</li> <li>Floodplain SLATS</li> </ul>                                                                                        |
|                                              | Floodplain recruitment & regeneration                   | <ul style="list-style-type: none"> <li>Floodplain regeneration index</li> </ul>                                                                                                           |
|                                              | Floodplain percent exotics                              | <ul style="list-style-type: none"> <li>Floodplain NATIVES Index</li> </ul>                                                                                                                |
| <b>Waterholes &amp; Wetlands</b>             |                                                         |                                                                                                                                                                                           |
| Waterhole & wetland biodiversity             | Macroinvertebrate assemblage composition                | <ul style="list-style-type: none"> <li>Taxa richness</li> <li>Modified SIGNAL score</li> <li>AusRivAS scores</li> </ul>                                                                   |
|                                              | Fish assemblage diversity                               | <ul style="list-style-type: none"> <li>% Native species</li> <li>% Exotic individuals</li> <li>Fish assemblage O/E</li> <li>Fish recruitment</li> </ul>                                   |
|                                              | Colonial water bird breeding – applies only to wetlands | <ul style="list-style-type: none"> <li>Breeding success</li> </ul>                                                                                                                        |
|                                              | Iconic species                                          | <ul style="list-style-type: none"> <li>Species under threat need further consideration e.g. frogs, turtles, water rat, monitor, brush tail possum, Cooper Creek catfish etc.</li> </ul>   |
|                                              | Mound springs – handled under GAB process               |                                                                                                                                                                                           |
|                                              | Cane toads                                              | <ul style="list-style-type: none"> <li>presence/absence</li> </ul>                                                                                                                        |
| Waterhole & wetland water quality            | Water quality                                           | <ul style="list-style-type: none"> <li>Conductivity (salinity)</li> <li>pH</li> <li>Turbidity</li> <li>Diel range in dissolved oxygen</li> <li>Diel range in water temperature</li> </ul> |
|                                              | Nutrients                                               | <ul style="list-style-type: none"> <li>Total N and P and available nutrients</li> </ul>                                                                                                   |
| Waterhole process & function                 | Ecosystem processes                                     | <ul style="list-style-type: none"> <li>Benthic metabolism</li> <li>Algal biomass &amp; composition</li> <li>Carbon &amp; nitrogen stable isotope analysis</li> </ul>                      |

1. In the Headwater (HW) region, as true floodplains do not exist, the measures would be undertaken on catchment vegetation.

# 7 Riverine Wetlands

## 7.5 Marine and Tropical Sciences Research Facility

The Marine and Tropical Sciences Research Facility (MTSRF) is supporting many projects to research the key environmental challenges facing the Great Barrier Reef and its catchments, tropical rainforests, including the Wet Tropics World Heritage Area, and the Torres Strait. Under the program heading 'Halting and reversing the decline of water quality', the project 'Freshwater indicators and thresholds of concern' is identifying and investigating appropriate indicators of waterway health to determine threshold levels at which water or habitat quality may become an ecological concern. Following a process of identification and elimination, a set of indicators (Table 24) has been tested against natural and disturbance gradients to determine if they are appropriate measures of condition in the wet tropics (R. Pearson pers. comm.). Further work may identify more biophysical indicators for testing.

## 7.6 Ecosystem Health Monitoring Program

The Freshwater Ecosystem Health Monitoring Program (EHMP) was established in Southeast Queensland to provide an objective assessment of the health of waterways throughout the region (Abal et al. 2005). The information collected is used to advise councils and land managers on areas of declining health, report on the effects of different land uses, and to evaluate the effectiveness of management actions aimed at improving and protecting aquatic ecosystems. Comprehensive indicators were developed that relate aquatic health to disturbance pressures through themes of fish, invertebrates, physico-chemical, eco-processes and nutrients. (Table 25). Monitoring is undertaken twice a year (autumn and spring) and the catchment results are disseminated to the general public via a 'report card'.

**Table 24. Biophysical indicators identified and tested against natural and disturbance gradients in the wet tropics for MTSRF.**

| Theme                                       | Indicator                                                                                                                                                                                                                                                                               |
|---------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Geomorphology                               | <ul style="list-style-type: none"> <li>• Bank stability</li> <li>• Degree of channel migration</li> <li>• Sediment characteristics</li> <li>• Bank modifications (levees etc)</li> <li>• Flow modifications</li> </ul>                                                                  |
| Riparian vegetation                         | <ul style="list-style-type: none"> <li>• % cover relative to natural</li> <li>• % native vegetation</li> <li>• % weed cover</li> <li>• Width</li> <li>• Disturbance score</li> </ul>                                                                                                    |
| Physical, chemical properties of water body | <ul style="list-style-type: none"> <li>• Flow</li> <li>• Temperature</li> <li>• Light environment</li> <li>• Conductivity</li> <li>• pH cycling</li> <li>• Clarity</li> <li>• Dissolved oxygen cycling</li> <li>• Nitrate concentration</li> </ul>                                      |
| Aquatic macrophytes                         | <ul style="list-style-type: none"> <li>• Total cover</li> <li>• Species richness</li> <li>• % submerged species</li> <li>• % emergent species</li> <li>• % native species</li> <li>• % alien species</li> <li>• % grass species</li> </ul>                                              |
| Aquatic invertebrates                       | <ul style="list-style-type: none"> <li>• Species richness</li> <li>• Family richness</li> </ul>                                                                                                                                                                                         |
| Fish                                        | <ul style="list-style-type: none"> <li>• Observed vs expected species richness and assemblage composition</li> <li>• Number of alien species</li> <li>• Percentage of fish species that are alien</li> <li>• Percentage of total fish abundance represented by alien species</li> </ul> |

# 7 Riverine Wetlands

**Table 25. Ecosystem Health Monitoring Program freshwater indicators and measures.**

| Indicator                  | Measure                                                                                                                                                                                        |
|----------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Physical/chemical          | <ul style="list-style-type: none"> <li>• pH</li> <li>• Conductivity</li> <li>• Diel (24hr) range and maximum temperature</li> <li>• Diel range and minimum dissolved oxygen</li> </ul>         |
| Nutrient cycling           | <ul style="list-style-type: none"> <li>• Ratio of 15N to 14N stable isotope</li> <li>• Algal bioassay</li> </ul>                                                                               |
| Ecosystem processes        | <ul style="list-style-type: none"> <li>• Growth rate of algae</li> <li>• Ratio of 13C to 12C stable isotopes</li> <li>• Respiration (R24)</li> <li>• Gross Primary Production (GPP)</li> </ul> |
| Aquatic macroinvertebrates | <ul style="list-style-type: none"> <li>• Number of macroinvertebrate taxa</li> <li>• EPT richness (number of stonefly, mayfly and caddisfly families)</li> <li>• SIGNAL score</li> </ul>       |
| Fish                       | <ul style="list-style-type: none"> <li>• Proportion of native species expected</li> <li>• Ratio of observed to expected species</li> <li>• Proportion of alien fish</li> </ul>                 |

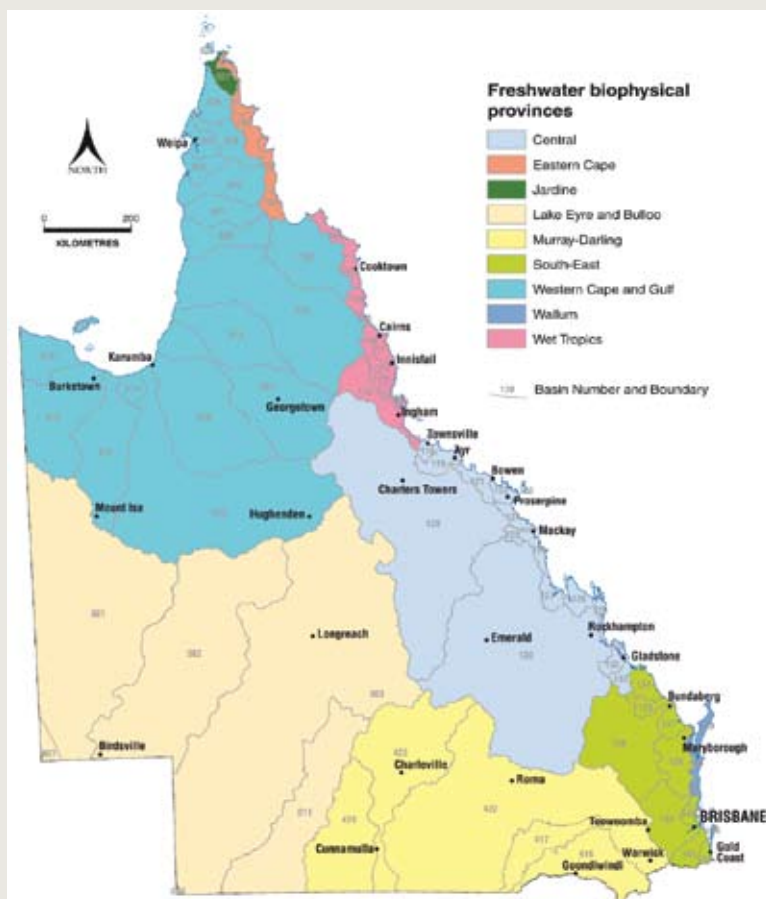
## 7.7 Ambient Biological Monitoring and Assessment Program

The Ambient Biological Monitoring and Assessment Program (ABMAP) is a statewide riverine monitoring program undertaken on an annual basis by the Department of Natural Resources & Water. The Queensland program commenced in 2001 and was based on the design of the National River Health Program (NRHP), a Commonwealth/State program which ran from 1994 to 2000 and developed a set of models (AusRivAS) to assess river health. The purpose of ABMAP is to monitor and assess the ecological

condition of Queensland's waterways to help guide natural resource management decisions. This is achieved through the use of aquatic macroinvertebrates as a biological indicator. In addition, physico-chemical water parameters are collected and extensive habitat information recorded.

Each year, two Freshwater Biogeographic Provinces (Figure 5) are selected for monitoring. Macroinvertebrates are collected using Queensland AusRivAS collecting protocols (NRW 2005; 2006a-i).

**Figure 5. Freshwater Biogeographic Provinces of Queensland.** The provinces were identified by analysis of macroinvertebrate data and tested using fish data.



# 7 Riverine Wetlands

## 7.8 Surface Water Ambient Network

The Surface Water Ambient Network (SWAN) is a statewide water quality monitoring program undertaken by the Department of Natural Resources & Water. Water samples are collected routinely from sites that are visited for stream gauging and analysed for physico-chemical properties and nutrients. Over 200 sites are visited up to four times a year. This information is used to evaluate the suitability of surface waters according to the methods described by ANZECC & ARMCANZ (2000) for the protection of slightly to moderately disturbed aquatic ecosystems (Grinter & Clarke 2006).

## 7.9 AquaBAMM

AquaBAMM (Aquatic Biodiversity Assessment and Mapping Method) is a decision support method developed by Queensland EPA to assess conservation values in aquatic ecosystems through existing information and expert opinion. The riverine component of AquaBAMM has been trialled and is now being applied to riverine systems in Queensland (Clayton et al. 2006). Whilst not strictly a method for determining resource condition, rather conservation values, criteria, indicators and measures are identified in the method. A comprehensive list of indicators and measures for riverine wetlands has been identified, based on information and datasets readily available in Queensland (Table 26) (P. Clayton pers. comm.).

**Table 26. AquaBAMM criteria, indicators and measures for riverine wetlands.**

| Indicators                                 | Measures                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|--------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>1. Naturalness Aquatic (Diagnostic)</b> |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| Exotic flora/fauna                         | <ul style="list-style-type: none"> <li>• Presence of 'alien' fish species within the wetland</li> <li>• Presence of exotic aquatic and semi-aquatic plants within the wetland</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                  |
| Aquatic communities/assemblages            | <ul style="list-style-type: none"> <li>• SOR<sup>1</sup> aquatic vegetation condition</li> <li>• SIGNAL<sup>2</sup> score (Max)</li> <li>• AUSRIVAS<sup>3</sup> score – Edge (Min band)</li> <li>• AUSRIVAS<sup>3</sup> score – Pool (Min band)</li> <li>• EPT<sup>4</sup> score (Max)</li> <li>• Wetland condition – as measured by an acknowledged condition metric</li> </ul>                                                                                                                                                                                                          |
| Habitat features modification              | <ul style="list-style-type: none"> <li>• SOR<sup>1</sup> bank stability</li> <li>• SOR<sup>1</sup> bed &amp; bar stability</li> <li>• SOR<sup>1</sup> aquatic habitat condition</li> <li>• Presence/absence of dams/weirs within the wetland</li> <li>• Inundation by dams/weirs (% of waterway length within the wetland)</li> <li>• Snag removal within the wetland</li> <li>• % area of remnant wetland relative to preclear extent for each spatial unit</li> <li>• Presence of dredging/extraction (including for navigation) and channel modification within the wetland</li> </ul> |

| Indicators                                   | Measures                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|----------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Hydrological modification                    | <ul style="list-style-type: none"> <li>• APFD<sup>5</sup> score – modelled deviation from natural under full development</li> <li>• Percent natural flows – modelled flows remaining relative to predevelopment</li> <li>• Percent no flows – modelled low flows relative to predevelopment</li> <li>• Mean annual extraction (or addition) (ML/year)</li> </ul>                                                                                                                                                                                     |
| Water quality                                | <ul style="list-style-type: none"> <li>• Median Total Phosphorous (ug/L)</li> <li>• Median Total Nitrogen (ug/L)</li> <li>• Median Turbidity (ug/L)</li> <li>• Median Conductivity (ug/L)</li> <li>• Median pH</li> <li>• Dissolved Oxygen (mg/L) within guideline limits (<i>expert panel list/discussion</i>)</li> <li>• Presence of harmful algal blooms (<i>expert panel list/discussion</i>)</li> <li>• Water quality index/score – an acknowledged metric calculated considering local, state or national water quality guidelines.</li> </ul> |
| <b>2. Naturalness Catchment (Diagnostic)</b> |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| Exotic flora/fauna                           | <ul style="list-style-type: none"> <li>• Presence of exotic terrestrial plants in the assessment unit</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Riparian disturbance                         | <ul style="list-style-type: none"> <li>• % area remnant vegetation relative to preclear extent within buffered riverine wetland or watercourses</li> <li>• Total number of Regional Ecosystems (RE) relative to preclear number of REs within buffered riverine wetland or watercourses</li> <li>• SOR<sup>1</sup> reach environs</li> <li>• SOR<sup>1</sup> riparian vegetation condition</li> </ul>                                                                                                                                                |
| Catchment disturbance                        | <ul style="list-style-type: none"> <li>• % 'agricultural' land-use area (i.e. cropping and horticulture)</li> <li>• % 'grazing' land-use area</li> <li>• % 'vegetation' land-use area (i.e. native veg + regrowth)</li> <li>• % 'settlement' land-use area (i.e. towns, cities, etc)</li> <li>• % area of known contaminated land adjacent to the wetland, measured within a 200 m buffer around the wetland</li> </ul>                                                                                                                              |
| Flow modification                            | <ul style="list-style-type: none"> <li>• Farm storage (overland flow harvesting, floodplain ring tanks, gully dams) calculated by surface area</li> <li>• % area of impervious surfaces within the assessment unit (typical of urban areas)</li> </ul>                                                                                                                                                                                                                                                                                               |

continued on next page

# 7 Riverine Wetlands

Table 26 continued from previous page

| Indicators                                                 | Measures                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>3. Diversity and Richness (Diagnostic)</b>              |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| Species                                                    | <ul style="list-style-type: none"> <li>• Richness of native amphibians (riverine wetland breeders)</li> <li>• Richness of native fish</li> <li>• Richness of native aquatic dependent reptiles</li> <li>• Richness of native waterbirds</li> <li>• Richness of native aquatic plants (macrophytes)</li> </ul>                                                                                                                                                                                                                                                                                                                |
| Communities/assemblages                                    | <ul style="list-style-type: none"> <li>• Number of macroinvertebrate taxa (Family level taxonomy)</li> <li>• Vegetation richness represented by richness of REs along riverine wetlands or watercourses within a specified buffer distance from the stream</li> <li>• Native fish biotic index (observed : expected ratio)</li> </ul>                                                                                                                                                                                                                                                                                        |
| Habitat                                                    | <ul style="list-style-type: none"> <li>• SOR<sup>1</sup> channel diversity</li> <li>• Richness of wetland types within the local catchment (e.g. SOR<sup>1</sup> sub-section)</li> <li>• Richness of wetland types within the sub-catchment</li> </ul>                                                                                                                                                                                                                                                                                                                                                                       |
| Geomorphology                                              | <ul style="list-style-type: none"> <li>• Richness of geomorphic features (i.e. features determined through a classification such as the GAR method)</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| <b>4. Threatened Species and Ecosystems (Diagnostic)</b>   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| Species                                                    | <ul style="list-style-type: none"> <li>• Presence of rare or threatened aquatic ecosystem dependent fauna species – NCA<sup>6</sup>, EPBCAct<sup>7</sup></li> <li>• Presence of rare or threatened aquatic ecosystem dependent flora species – NCA<sup>6</sup>, EPBCAct<sup>7</sup></li> </ul>                                                                                                                                                                                                                                                                                                                               |
| Communities/assemblages                                    | <ul style="list-style-type: none"> <li>• Conservation status of wetland Regional Ecosystems – Herbarium biodiversity status, NCA<sup>6</sup>, EPBCAct<sup>7</sup></li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| <b>5. Priority Species and Ecosystems (Expert opinion)</b> |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| Species                                                    | <ul style="list-style-type: none"> <li>• Presence of aquatic ecosystem dependent 'priority' fauna species (<i>expert panel list/discussion</i> or other lists such as ASFB<sup>8</sup>, WWF<sup>9</sup>, etc)</li> <li>• Presence of aquatic ecosystem dependent 'priority' flora species (<i>expert panel list/discussion</i>)</li> <li>• Habitat for, or presence of, migratory species (<i>expert Panel list/discussion</i> and/or JAMBA<sup>10</sup> / CAMBA<sup>11</sup> agreement lists and Bonn Convention)</li> <li>• Habitat for significant numbers of waterbirds (<i>expert panel list/discussion</i>)</li> </ul> |
| Ecosystems                                                 | <ul style="list-style-type: none"> <li>• Presence of 'priority' aquatic ecosystem (<i>expert panel list/discussion</i>)</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |

| Indicators                                  | Measures                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
|---------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>6. Special Features (Expert opinion)</b> |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| Geomorphic features                         | <ul style="list-style-type: none"> <li>• Presence of distinct, unique or special geomorphic features (<i>expert panel list/discussion</i>)</li> </ul>                                                                                                                                                                                                                                                                                                                                                                  |
| Ecological processes                        | <ul style="list-style-type: none"> <li>• Presence of (or requirement for) distinct, unique or special ecological processes (<i>expert panel list/discussion</i>)</li> </ul>                                                                                                                                                                                                                                                                                                                                            |
| Habitat                                     | <ul style="list-style-type: none"> <li>• Presence of distinct, unique or special habitat (including habitat that functions as refugia or other critical purpose) (<i>expert panel list/discussion</i>)</li> <li>• Significant wetlands identified by an accepted method such as Ramsar, Australian Directory of Important Wetlands, Regional Coastal Management Planning, World Heritage Areas, etc.</li> <li>• Ecologically significant wetlands identified through expert opinion and/or documented study</li> </ul> |
| Hydrological                                | <ul style="list-style-type: none"> <li>• Presence of distinct, unique or special hydrological regimes (eg. Spring fed stream, ephemeral stream, boggomoss) (<i>expert panel list/discussion</i>)</li> </ul>                                                                                                                                                                                                                                                                                                            |
| <b>7. Connectivity (Expert opinion)</b>     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| Significant species or populations          | <ul style="list-style-type: none"> <li>• The contribution (upstream or downstream) of the spatial unit to the maintenance of significant species or populations, including those features identified through Criteria 5 and/or 6 (<i>expert panel list/discussion</i>)</li> <li>• Possibility for migratory or routine 'passage' of fish and other fully aquatic species (upstream, lateral or downstream movement) within the spatial unit</li> </ul>                                                                 |
| Groundwater dependent ecosystems            | <ul style="list-style-type: none"> <li>• The contribution (upstream or downstream) of the spatial unit to the maintenance of groundwater ecosystems with significant biodiversity values, including those features identified through Criteria 5 and/or 6 (e.g., karsts, cave streams, artesian springs) (<i>expert panel list/discussion</i>)</li> </ul>                                                                                                                                                              |
| Floodplain and wetland ecosystems           | <ul style="list-style-type: none"> <li>• The contribution of the spatial unit to the maintenance of floodplain and wetland ecosystems with significant biodiversity values, including those features identified through Criteria 5 and/or 6 (<i>expert panel list/discussion</i>)</li> </ul>                                                                                                                                                                                                                           |
| Estuarine and marine ecosystems             | <ul style="list-style-type: none"> <li>• The contribution of the spatial unit to the maintenance of estuarine and marine ecosystems with significant biodiversity values, including those features identified through Criteria 5 and/or 6 (<i>expert panel list/discussion</i>)</li> </ul>                                                                                                                                                                                                                             |

1.State of the Rivers; 2.Stream Invertebrate Grade Number – Average Level; 3.Australian River Assessment System; 4.Ephemeroptera, Plecoptera, Trichoptera; 5.Annual Proportional Flow Deviation; 6.Nature Conservation Act; 7.Environment Protection and Biodiversity Conservation Act 1999; 8.Australian Society for Fish Biology; 9.World Wildlife Fund; 10.Japan–Australia Migratory Bird Agreement; 11.China–Australia Migratory Bird Agreement.

# 7 Riverine Wetlands

## 7.10 Rapid Appraisal of Riparian Condition and Tropical Rapid Appraisal of Riparian Condition

The Rapid Appraisal of Riparian Condition (RARC) and the Tropical Rapid Appraisal of Riparian Condition (TRARC) are methods that have been developed to assess the health of riverine riparian zones (Jansen et al. 2005; Dixon et al. 2006). Both methods derive an index of condition using indicators to reflect functional aspects of the physical, community and landscape features of the riparian zone. These methods have been designed specifically for riverine riparian zones and can be used by operators with limited scientific training. Their

purpose is to inform land managers on the condition of their riparian zones and assist in their management.

The RARC method was developed for South-east Australia, and has shown a good negative relationship between grazing intensity and riparian condition. Testing of RARC in tropical areas of Australia showed that the relationships were not as strong, leading to the development of the TRARC method. The indicators and measures for RARC are listed in Table 27; TRARC indicators and measures are in Table 28.

**Table 27. RARC sub-indices and indicators.**

| Sub-Index | Indicator                                                                                                                                                                                                     |
|-----------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Habitat   | <ul style="list-style-type: none"><li>• Longitudinal continuity of riparian vegetation</li><li>• Width of riparian vegetation</li><li>• Proximity to nearest patch of intact native vegetation</li></ul>      |
| Cover     | <ul style="list-style-type: none"><li>• Canopy (&gt;5 m tall)</li><li>• Understorey (1-5 m tall)</li><li>• Ground (&lt;1 m tall)</li><li>• Number of layers</li></ul>                                         |
| Natives   | <ul style="list-style-type: none"><li>• Canopy (&gt;5 m tall)</li><li>• Understorey (1-5 m tall)</li><li>• Ground (&lt;1 m tall)</li></ul>                                                                    |
| Debris    | <ul style="list-style-type: none"><li>• Leaf litter</li><li>• Native leaf litter</li><li>• Standing dead trees (&gt;20 cm dbh)</li><li>• Hollow-bearing trees</li><li>• Fallen logs (&gt;10 cm dbh)</li></ul> |
| Features  | <ul style="list-style-type: none"><li>• Native canopy species regeneration (&lt;1 m tall)</li><li>• Native understorey regeneration</li><li>• Large native tussock grass</li><li>• Reeds</li></ul>            |

**Table 28. TRARC sub-indices, indicators and measures.**

| Sub-Index    | Indicator                                                                                                                                                                                                              | Measure                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
|--------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Plant Cover  | <ul style="list-style-type: none"> <li>• Canopy cover</li> <li>• Canopy continuity</li> <li>• Midstorey cover</li> <li>• Understorey cover</li> <li>• Grass cover</li> <li>• Organic litter</li> <li>• Logs</li> </ul> | <ul style="list-style-type: none"> <li>• Percentage cover of trees &gt;5 m tall</li> <li>• Percentage of longitudinal bank covered with trees &gt;5 m tall</li> <li>• Percentage cover of vegetation 1.5 – 5 m tall</li> <li>• Percentage cover of vegetation &lt;1.5 m tall</li> <li>• Percentage cover of grass</li> <li>• Percentage cover of leaves and fallen branches &lt;10 cm diameter</li> <li>• Abundance of logs &gt;10 cm diameter</li> </ul>                                                                                                             |
| Regeneration | <ul style="list-style-type: none"> <li>• Canopy health</li> <li>• Large trees</li> <li>• Tree size classes</li> <li>• Dominant tree regeneration</li> <li>• Other tree regeneration</li> </ul>                         | <ul style="list-style-type: none"> <li>• Appearance of canopy health</li> <li>• Abundance of trees with trunk diameter &gt;30 cm</li> <li>• Variation in tree trunk width</li> <li>• Abundance of juveniles 0.3–3 m</li> <li>• Abundance of juveniles 0.3–3 m</li> </ul>                                                                                                                                                                                                                                                                                              |
| Weeds        | <ul style="list-style-type: none"> <li>• Canopy weeds</li> <li>• Midstorey weeds</li> <li>• Understorey weeds</li> <li>• Grass weeds</li> <li>• Organic litter weeds</li> </ul>                                        | <ul style="list-style-type: none"> <li>• Proportion of weed versus native canopy cover</li> <li>• Proportion of weed versus native midstorey cover</li> <li>• Proportion of weed versus native understorey cover</li> <li>• Proportion of weed versus native grass cover</li> <li>• Proportion of weed versus native organic litter cover</li> </ul>                                                                                                                                                                                                                  |
|              | <ul style="list-style-type: none"> <li>• High impact weeds</li> <li>• High impact weed distribution</li> </ul>                                                                                                         | <ul style="list-style-type: none"> <li>• Presence of listed weed species</li> <li>• Distribution pattern of listed weed species within the riparian transect</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                               |
| Erosion      | <ul style="list-style-type: none"> <li>• Exposed soil</li> <li>• Exposed tree roots</li> <li>• Slumping</li> <li>• Gullying</li> <li>• Undercutting</li> </ul>                                                         | <ul style="list-style-type: none"> <li>• Percentage cover of exposed soil/sand/ash</li> <li>• Extent of exposed roots due to erosion</li> <li>• Combined width of slumps</li> <li>• Combined width of gullies</li> <li>• Combined width of undercuts</li> </ul>                                                                                                                                                                                                                                                                                                       |
| Pressure     | <ul style="list-style-type: none"> <li>• Bank stability</li> <li>• Animals: managed and unmanaged</li> <li>• Fire</li> <li>• Tree clearing</li> <li>• Flow regime</li> <li>• Other</li> </ul>                          | <ul style="list-style-type: none"> <li>• Bank slope</li> <li>• Instream structures: abundance of human-built instream structures</li> <li>• Dominant and maximum bank sediment size</li> <li>• Extent of impact due to managed animals (e.g. stock) and unmanaged animals (e.g. feral pigs)</li> <li>• Time since fire and spatial impact of fire</li> <li>• Proximity of clearing to river bank and width of clearing</li> <li>• Reduction of plant regeneration due to large dams</li> <li>• Extent of damage from human built structures and activities</li> </ul> |

# 8 Estuarine and Marine Wetlands

Estuarine wetlands are those wetlands that have oceanic water that is at least occasionally diluted with freshwater runoff from the land. Within channels, that is generally below the point of the upstream limit of tidal influence at mean high water springs (MHWS). Outside channels (e.g. within an embayment, at a river mouth), the upper limit of an estuarine system is defined as the landward limit of tidal inundation or highest astronomical tide (HAT) (EPA 2005b).

Marine wetlands are open ocean overlying the continental shelf and its associated high energy coastline down to a depth of 6 m below lowest astronomical tide (LAT), where salinities exceed 33 ppt with little or no dilution outside the mouths of estuaries. The marine system also includes shallow coastal bays with no appreciable freshwater inflow, coasts with exposed rocky islands that provide the mainland with little or no shelter from wind or waves, and coral reefs. Marine habitats are exposed to the waves and currents of the open ocean, and the water regimes are determined by the ebb and flow of oceanic tides (EPA 2005b).

## 8.1 Natural Resource Management (NRM) Resource Condition Indicators

In 2004 the CRC Coastal Zone proposed a new set of resource condition indicators for the Estuarine, coastal and marine (ECM) Matter for Target in the draft document *Users' Guide to Estuarine, Coastal and Marine Indicators for Regional NRM Monitoring* (Scheltinga et al. 2004). The work was commissioned by the Australian Government to inform the Monitoring and Evaluation Working Group (MEWG) and the Intergovernmental Coastal Advisory Group (ICAG). The purpose of the review was to identify indicators that are relevant to NRM regions to meet monitoring needs specified under the Natural Heritage Trust and the National Action Plan for Salinity and Water Quality (NAP). A total of 31 indicators were identified (Table 29), as well as a pressure, stressor, response framework for selecting indicators, which relied upon conceptual models of stressors to illustrate the relationships between the natural resources, ecological processes, and stressors. Stressors can be physical, chemical or biological components of the environment that can be altered by human or other activities (pressures), resulting in degradation to natural resources (response).

**Table 29. Current recommended indicators for Estuarine, Coastal and Marine Matter for Target.**

| Indicator Heading                                                                               | Recommended Indicators                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|-------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Estuarine, coastal and marine habitat extent and distribution<br>(Indicator Status: For Advice) | <ul style="list-style-type: none"> <li>Algal blooms (Indicator Status: For advice)</li> <li>Animal disease/lesions (Indicator status: for advice)</li> <li>Animal kills (Indicator Status: For advice)</li> <li>Animal or plant species abundance (Indicator Status: For advice)</li> <li>Animals killed or injured by litter (entanglement, starvation, suffocation) (Indicator Status: For advice)</li> <li>Benthic microalgae biomass (in intertidal sand/mudflat communities) (Indicator Status: For advice)</li> <li>Biomass, or number per unit area, of epiphytes (in seagrass or mangrove communities) (Indicator Status: For advice)</li> <li>Biomass, or number per unit area, of macroalgae (in rocky shore, rocky reef or coral reef communities) (Indicator Status: For advice)</li> </ul> |

| Indicator Heading                               | Recommended Indicators                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
|-------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                 | <ul style="list-style-type: none"> <li>• Chlorophyll a (Indicator Status: For advice)</li> <li>• Coral bleaching (Indicator Status: For advice)</li> <li>• Death of marine mammals, endangered sharks and reptiles caused by boat strike, shark nets or drum lines (Indicator Status: For advice)</li> <li>• Dissolved Oxygen (DO) (Indicator Status: For advice)</li> <li>• Estuary mouth opening/closing (Indicator Status: For advice)</li> <li>• Extent/distribution of key habitat types (Indicator Status: For advice)</li> <li>• Extent/distribution of subtidal macroalgae (Indicator Status: For advice)</li> <li>• Occurrence of imposex (Indicator Status: For advice)</li> <li>• Pest species (number, density, distribution) (Indicator Status: For advice)</li> <li>• pH (Indicator Status: For advice)</li> <li>• Presence/extent of litter (Indicator Status: For advice)</li> <li>• Salinity (Indicator Status: For advice)</li> <li>• Seagrass: depth range (Indicator Status: For advice)</li> <li>• Sedimentation/erosion rates (Indicator Status: For advice)</li> <li>• Targeted pathogen counts (Indicator Status: For advice)</li> <li>• Total nutrients in the sediment WITH dissolved nutrients in the sediment (Indicator Status: For advice)</li> <li>• Total nutrients in the water column WITH dissolved nutrients in the water column (Indicator Status: For advice)</li> <li>• Toxicants in biota (Indicator Status: For advice)</li> <li>• Toxicants in the sediment (Indicator Status: For advice)</li> <li>• Turbidity/water clarity (Indicator Status: For advice)</li> <li>• Water-current patterns (Indicator Status: For advice)</li> <li>• Water soluble toxicants in the water column (Indicator Status: For advice)</li> <li>• Water temperature (Indicator Status: For advice)</li> </ul> |
| Estuarine, coastal and marine habitat condition | Condition of habitat at significant sites of selected estuarine, coastal and marine habitats (Indicator Status: Unclear)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |

Due to the disbandment of the MEWG in 2004, the status of this list has remained as 'For advice'. The NLWRA took over the tasks of the MEWG and the review of the ECM indicators was resumed with a national workshop in 2006. A nationally agreed set of 19 indicators was developed at the workshop (Souter & Mackenzie 2006) and further refined by ICAG (Table 30) (R. Thorman pers. comm.; Scheltinga & Moss in prep.a). Trials of the indicators commenced in Tasmania, South Australia and Queensland in 2006. The original 2004 list, and associated methods, is still accessible on the Natural Resource Management website although it has been removed from the NLWRA resource condition indicators webpage in preparation for a new list of recommended indicators once the trials have finished.

# 8 Estuarine and Marine Wetlands

**Table 30. Proposed indicators for Estuarine, Coastal and Marine Matter for Target, and measures currently undergoing trials in Queensland (R. Thorman pers.comm.; Scheltinga & Moss in prep.a).**

| Indicator                                                            | Measures (Qld trials)                                                                                                                                                                                                                                                                                                                                                              |
|----------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Estuarine, coastal and marine habitat extent and distribution</b> |                                                                                                                                                                                                                                                                                                                                                                                    |
| 1 Extent and distribution of key habitat types                       | Key habitat types: <ul style="list-style-type: none"> <li>• Coral reef</li> <li>• Mangrove</li> <li>• Saltmarsh</li> <li>• Seagrass</li> </ul>                                                                                                                                                                                                                                     |
| <b>Estuarine, coastal and marine habitat condition</b>               |                                                                                                                                                                                                                                                                                                                                                                                    |
| <b>Biological Condition</b>                                          |                                                                                                                                                                                                                                                                                                                                                                                    |
| 2 Algal blooms                                                       | <ul style="list-style-type: none"> <li>• Presence of algal bloom based on regular visual observation.</li> <li>• Species level identification of dominant species.</li> </ul>                                                                                                                                                                                                      |
| 3 Animal or plant species abundance                                  | <ul style="list-style-type: none"> <li>• Abundance and biodiversity of fish, crab and prawn.</li> </ul>                                                                                                                                                                                                                                                                            |
| 4 Chlorophyll a                                                      | <ul style="list-style-type: none"> <li>• Concentration of Chlorophyll a in the photic zone of the waterbody.</li> </ul>                                                                                                                                                                                                                                                            |
| 5 Coral bleaching                                                    |                                                                                                                                                                                                                                                                                                                                                                                    |
| 6 Mass mortality events                                              | <ul style="list-style-type: none"> <li>• Presence of fish kill based on visual observation</li> </ul>                                                                                                                                                                                                                                                                              |
| 7 Pest species (number, density, distribution)                       | <ul style="list-style-type: none"> <li>• Identify number, density and distribution of pest species – extent of each species should be categorised as:               <ul style="list-style-type: none"> <li>- Uncommon</li> <li>- Common but with no apparent ecological impact</li> <li>- Common and with significant ecological impact</li> <li>- Abundant</li> </ul> </li> </ul> |
| 8 Targeted pathogen counts                                           | Intestinal enterococci counts: <ul style="list-style-type: none"> <li>• 95<sup>th</sup> value for intestinal enterococci/100 mL, based on a minimum of 5 samples</li> </ul>                                                                                                                                                                                                        |
| 9 Vertebrates impacted by human activities                           | <ul style="list-style-type: none"> <li>• Number of reported impact incidents for each species relative to estimated total local populations for each species.</li> </ul>                                                                                                                                                                                                           |
| <b>Physical/chemical condition</b>                                   |                                                                                                                                                                                                                                                                                                                                                                                    |
| 10 Dissolved oxygen                                                  | <ul style="list-style-type: none"> <li>• Dissolved oxygen concentration in the surface water measured during the middle of the day and expressed as percent saturation.</li> <li>• Dissolved oxygen concentrations in surface waters measured just before daylight.</li> </ul>                                                                                                     |

| Indicator                               | Measures (Qld trials)                                                                                                                                                                                                                     |
|-----------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 11 Nutrients                            | <ul style="list-style-type: none"> <li>Concentration of soluble or total Nitrogen or Phosphorus in a surface water sample</li> </ul>                                                                                                      |
| 12 pH                                   | <ul style="list-style-type: none"> <li>pH of surface waters – collected throughout the waterbody at least once daily during the 4 days following an event and the lowest value of these to be recorded as the indicator result</li> </ul> |
| 13 Presence/extent of litter            | <ul style="list-style-type: none"> <li>Type and extent of litter</li> </ul>                                                                                                                                                               |
| 14 Salinity (EC)                        | <ul style="list-style-type: none"> <li>Annual median salinity levels in the surface and bottom waters of the major functional zones of the waterbody under study</li> </ul>                                                               |
| 15 Sedimentation/erosion rates          |                                                                                                                                                                                                                                           |
| 16 Shoreline position                   |                                                                                                                                                                                                                                           |
| 17 Temperature                          |                                                                                                                                                                                                                                           |
| 18 Toxicants (in water/sediments/biota) | <ul style="list-style-type: none"> <li>Levels of toxicants in sediments in each major functional zone of the estuary or coastal waterbody</li> </ul>                                                                                      |
| 19 Turbidity/water clarity              | (Measure not yet identified)                                                                                                                                                                                                              |

## 8.2 Stream and Estuarine Assessment Program (SEAP)

Sections 6.1 and 7.2 of this document discussed elements of the Stream and Estuarine Assessment Program (SEAP), which is under development by two Queensland Government agencies (Natural Resources & Water (NRW) and Environmental Protection Agency (EPA)). It will eventually replace the current state-wide water quality monitoring programs run by those agencies. It is a hypothesis-based program where conceptual models will be developed to explain how Queensland's aquatic ecosystems respond to particular human activities, and the biophysical changes to the aquatic environment resulting from the activities. NRW is developing the freshwater component of the program and EPA the estuarine.

The estuarine component of the SEAP has been developed in conjunction with the NLWRA review of Matters for Target (Section 8.1). Conceptual models of estuaries and coastal zones were developed by the CRC Coastal Zone (OzCoasts and OzEstuaries). These have been used to identify stressors and indicators that are currently being tested. SEAP development has

been slightly more intricate compared to the NRM resource condition indicators review, although the principles are the same. SEAP has developed conceptual models for stressors that are common in Queensland, and identified indicators for each phase of the models (pressure, stressor, response) (Table 31) (Scheltinga & Moss in prep.b). Four types of indicators have been identified:

- Human activities that result in a change to the stressor (i.e. the pressure).
- A direct measure of the stressor e.g. nutrient load entering a waterbody.
- The change in physical-chemical condition caused by the changing stressor (response).
- The change in biological condition observed as a result of the change in physical-chemical condition (response).

There may be many pathways in which a stressor may occur, hence many indicators may be identified. Many of the proposed SEAP indicators are the same as those identified for the NRM resource condition indicators review, and the proposed methods are comparable.

# 8 Estuarine and Marine Wetlands

**Table 31. Proposed SEAP stressors (and direct pressures on the system) and indicators for each phase of the models (Scheltinga & Moss in prep.b).**

| Pressure Indicators                                                                                                                                                                                                                                                                                                                   |                                                                                                                                                                                          | Condition Indicators                                                              |                                                                                                                                                                               |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Stressor Source                                                                                                                                                                                                                                                                                                                       | Direct Pressure                                                                                                                                                                          | Physical/Chemical                                                                 | Biological                                                                                                                                                                    |
| <b>Aquatic Sediments (Suspended Sediment Loads)</b>                                                                                                                                                                                                                                                                                   |                                                                                                                                                                                          |                                                                                   |                                                                                                                                                                               |
| <ul style="list-style-type: none"> <li>Catchment land-use</li> <li>Percentage of catchment cleared</li> <li>Percentage length of river system with no riparian vegetation</li> <li>Presence of point sources</li> <li>Number of boats using estuary</li> </ul>                                                                        | <ul style="list-style-type: none"> <li>Monitored or modelled sediment loads entering the estuary (total diffuse and point sources)</li> <li>Occurrence of dredging in estuary</li> </ul> | <ul style="list-style-type: none"> <li>Secchi depth</li> <li>Turbidity</li> </ul> | <ul style="list-style-type: none"> <li>Change in seagrass extent</li> <li>Percentage cover of seagrass.</li> <li>Change in mangrove extent</li> </ul>                         |
| <b>Bacteria/Pathogen (Bacteria/Pathogen Loads)</b>                                                                                                                                                                                                                                                                                    |                                                                                                                                                                                          |                                                                                   |                                                                                                                                                                               |
| <ul style="list-style-type: none"> <li>Occurrence of sewage treatment plants</li> <li>Occurrence of sewage overflow events</li> <li>Number of intensive animal production sites within catchment</li> <li>Number of septic tanks within catchment</li> </ul>                                                                          | None                                                                                                                                                                                     | <ul style="list-style-type: none"> <li>Intestinal enterococci counts</li> </ul>   | None                                                                                                                                                                          |
| <b>Biota Removal or Disturbance</b>                                                                                                                                                                                                                                                                                                   |                                                                                                                                                                                          |                                                                                   |                                                                                                                                                                               |
| <ul style="list-style-type: none"> <li>Occurrence of bait collecting in estuary</li> <li>Occurrence of trawling in estuary</li> <li>Number of boats moored in estuary</li> <li>Number of boats using estuary</li> <li>Recreational usage index</li> <li>Coastal population size</li> <li>Occurrence of dredging in estuary</li> </ul> | None                                                                                                                                                                                     | None                                                                              | <ul style="list-style-type: none"> <li>Fish, crab and prawn abundance or biodiversity</li> <li>Vertebrates inadvertently impacted by human activities (not litter)</li> </ul> |

| Pressure Indicators                                                                                                                                                                                                                      |                                                                                                  | Condition Indicators |                                                                                                                                                                               |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------|----------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Stressor Source                                                                                                                                                                                                                          | Direct Pressure                                                                                  | Physical/Chemical    | Biological                                                                                                                                                                    |
| <ul style="list-style-type: none"> <li>Number of recreational fishers using estuary</li> <li>Number of commercial fishers using estuary</li> <li>Number of licensed collectors (of aquarium fish, shells, etc.) using estuary</li> </ul> | None                                                                                             | None                 | <ul style="list-style-type: none"> <li>Fish, crab and prawn abundance or biodiversity</li> <li>Vertebrates inadvertently impacted by human activities (not litter)</li> </ul> |
| <b>Freshwater Flow Regime</b>                                                                                                                                                                                                            |                                                                                                  |                      |                                                                                                                                                                               |
| <ul style="list-style-type: none"> <li>Number of times freshwater flow greater than estuary volume (complete estuary flush)</li> <li>Percentage of median annual flow impounded and extracted</li> </ul>                                 | None                                                                                             | None                 | None                                                                                                                                                                          |
| <b>Habitat Removal or Disturbance</b>                                                                                                                                                                                                    |                                                                                                  |                      |                                                                                                                                                                               |
| <ul style="list-style-type: none"> <li>Number of impoundments without fish ladders</li> <li>Occurrence of dredging in estuary</li> <li>Percentage of catchment under aquaculture</li> </ul>                                              | <ul style="list-style-type: none"> <li>Percentage of estuarine riparian area modified</li> </ul> | None                 | <ul style="list-style-type: none"> <li>Change in seagrass extent</li> <li>Change in mangrove extent</li> <li>Change in saltmarsh extent</li> </ul>                            |
| <b>Hydrodynamics</b>                                                                                                                                                                                                                     |                                                                                                  |                      |                                                                                                                                                                               |
| <ul style="list-style-type: none"> <li>Presence of entrance modifications</li> <li>Presence of canals, piers, other estuary modifications</li> <li>Presence of tidal barrages</li> <li>Occurrence of dredging in estuary</li> </ul>      | None                                                                                             | None                 | None                                                                                                                                                                          |

continued on next page

# 8 Estuarine and Marine Wetlands

Table 31 continued from previous page

| Pressure Indicators                                                                                                                                                                                                                                                            |                                                                                                                                               | Condition Indicators                                                                                                                                |                                                                                                                                                                                                                                    |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Stressor Source                                                                                                                                                                                                                                                                | Direct Pressure                                                                                                                               | Physical/Chemical                                                                                                                                   | Biological                                                                                                                                                                                                                         |
| <b>Litter</b>                                                                                                                                                                                                                                                                  |                                                                                                                                               |                                                                                                                                                     |                                                                                                                                                                                                                                    |
| <ul style="list-style-type: none"> <li>Catchment land-use</li> <li>Coastal population size</li> <li>Number of boats using estuary</li> <li>Recreational usage index</li> <li>Percentage of stormwater outflows within catchment using best management practices</li> </ul>     | None                                                                                                                                          | <ul style="list-style-type: none"> <li>Presence of litter</li> </ul>                                                                                | <ul style="list-style-type: none"> <li>Vertebrates killed by litter</li> </ul>                                                                                                                                                     |
| <b>Nutrients Loads</b>                                                                                                                                                                                                                                                         |                                                                                                                                               |                                                                                                                                                     |                                                                                                                                                                                                                                    |
| <ul style="list-style-type: none"> <li>Catchment land-use</li> <li>Percentage length of river system with no riparian vegetation</li> <li>Occurrence of sewage treatment plants</li> <li>Occurrence of sewage overflow events</li> </ul>                                       | <ul style="list-style-type: none"> <li>Monitored or modelled nutrient loads entering the estuary (total diffuse and point sources)</li> </ul> | <ul style="list-style-type: none"> <li>Nitrate</li> <li>Filterable reactive phosphorus</li> <li>Total nitrogen</li> <li>Total phosphorus</li> </ul> | <ul style="list-style-type: none"> <li>Chlorophyll-a</li> <li>Percentage epiphytic cover on seagrass</li> <li>Percentage macroalgal cover on coral reef</li> <li>Percentage macroalgal cover on mangrove pneumatophores</li> </ul> |
| <b>Organic Matter Loads</b>                                                                                                                                                                                                                                                    |                                                                                                                                               |                                                                                                                                                     |                                                                                                                                                                                                                                    |
| <ul style="list-style-type: none"> <li>Catchment land-use</li> <li>Presence of point sources</li> <li>Occurrence of sewage overflow events</li> <li>Percentage of catchment under intensive livestock</li> <li>Percentage of river system affected by aquatic weeds</li> </ul> | <ul style="list-style-type: none"> <li>BOD<sub>5</sub> load</li> </ul>                                                                        | <ul style="list-style-type: none"> <li>Dissolved oxygen</li> </ul>                                                                                  | <ul style="list-style-type: none"> <li>Number of mass mortality events caused by low dissolved oxygen</li> </ul>                                                                                                                   |

| Pressure Indicators                                                                                                                                                                                                            |                                                                                                                    | Condition Indicators                                                                                                                                 |                                                                                                                                                        |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------|
| Stressor Source                                                                                                                                                                                                                | Direct Pressure                                                                                                    | Physical/Chemical                                                                                                                                    | Biological                                                                                                                                             |
| <b>Pest Species (Pest Species Introduction)</b>                                                                                                                                                                                |                                                                                                                    |                                                                                                                                                      |                                                                                                                                                        |
| <ul style="list-style-type: none"> <li>• Presence of pest species in adjacent areas</li> <li>• Presence of port/harbour/marina</li> <li>• Presence of aquaculture facilities using species non-native to the region</li> </ul> | None                                                                                                               | <ul style="list-style-type: none"> <li>• Occurrence of pest species</li> </ul>                                                                       | None                                                                                                                                                   |
| <b>pH (Acid Sulphate Soil Run-off)</b>                                                                                                                                                                                         |                                                                                                                    |                                                                                                                                                      |                                                                                                                                                        |
| <ul style="list-style-type: none"> <li>• Areal extent of disturbed acid sulphate soils</li> </ul>                                                                                                                              | None                                                                                                               | <ul style="list-style-type: none"> <li>• Minimum sustained pH values during the days following an inflow event</li> </ul>                            | <ul style="list-style-type: none"> <li>• Number of mass mortality events caused by low pH</li> <li>• Occurrence of red-spot disease of fish</li> </ul> |
| <b>Toxicant Loads</b>                                                                                                                                                                                                          |                                                                                                                    |                                                                                                                                                      |                                                                                                                                                        |
| <ul style="list-style-type: none"> <li>• Catchment land-use</li> <li>• Percentage of catchment under mining lease</li> <li>• Presence of point sources</li> <li>• Number of commercial boats using estuary</li> </ul>          | <ul style="list-style-type: none"> <li>• Amount of oil spilled and number of oil slicks/spills reported</li> </ul> | <ul style="list-style-type: none"> <li>• Toxicants in the water column</li> <li>• Toxicants in the sediment</li> <li>• Toxicants in biota</li> </ul> | <ul style="list-style-type: none"> <li>• Number of mass mortality events caused by toxicants</li> </ul>                                                |

## 8 Estuarine and Marine Wetlands

### 8.3 EPA monitoring

Queensland EPA undertakes regular water quality monitoring in the rivers, estuaries and coastal areas of Eastern Queensland. The data collected is used by EPA to assist in managing those areas. The indicators and measures are listed in Table 32; methods are available from the Water Quality Sampling Manual (EPA 1999).

### 8.4 Ecosystem Health Monitoring Program

The estuarine/marine component of the Ecosystem Health Monitoring Program (EHMP) undertakes regular monitoring of several indicators that were selected on the basis of an understanding of Moreton Bay and its associated waterways, and the pressures and stressors in that environment. EHMP indicators and measures are listed in Table 33.

[http://www.ehmp.org/estuarinemarine\\_monitoring.html](http://www.ehmp.org/estuarinemarine_monitoring.html)

**Table 32. Water quality indicators and measures collected by the EPA in rivers, estuaries and coastal areas of eastern Queensland.**

| Theme                 | Indicators and measures                                                                                                                                                              |
|-----------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Nutrients             | <ul style="list-style-type: none"><li>• Nitrogen<ul style="list-style-type: none"><li>o Organic</li><li>o Nitrate plus nitrite</li><li>o Ammonia</li><li>o Total</li></ul></li></ul> |
|                       | <ul style="list-style-type: none"><li>• Phosphorus<ul style="list-style-type: none"><li>o Filterable reactive</li><li>o Total</li></ul></li></ul>                                    |
| Microalgal Growth     | <ul style="list-style-type: none"><li>• Chlorophyll-a</li></ul>                                                                                                                      |
| Water Clarity         | <ul style="list-style-type: none"><li>• Suspended solids</li></ul>                                                                                                                   |
|                       | <ul style="list-style-type: none"><li>• Turbidity</li></ul>                                                                                                                          |
|                       | <ul style="list-style-type: none"><li>• Secchi depth</li></ul>                                                                                                                       |
| Oxygen                | <ul style="list-style-type: none"><li>• Dissolved oxygen</li></ul>                                                                                                                   |
| pH                    | <ul style="list-style-type: none"><li>• pH</li></ul>                                                                                                                                 |
| Salinity              | <ul style="list-style-type: none"><li>• Conductivity</li></ul>                                                                                                                       |
| Toxicants in sediment | <ul style="list-style-type: none"><li>• Trace elements in sediments</li></ul>                                                                                                        |
|                       | <ul style="list-style-type: none"><li>• Pesticides in sediments</li></ul>                                                                                                            |
| Recreational health   | <ul style="list-style-type: none"><li>• Faecal coliforms</li></ul>                                                                                                                   |

**Table 33. Indicators and measures used in the estuarine/marine component of the EHMP.**

| Theme                                 | Indicators and measures                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|---------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Water Quality                         | <ul style="list-style-type: none"> <li>• Physico-chemical               <ul style="list-style-type: none"> <li>o Turbidity</li> <li>o Dissolved oxygen</li> <li>o Salinity</li> <li>o pH</li> <li>o Water temperature</li> </ul> </li> <li>• Nutrients               <ul style="list-style-type: none"> <li>o Total nitrogen</li> <li>o Total phosphorus</li> <li>o Oxides of nitrogen</li> <li>o Ammonium</li> <li>o Filterable reactive phosphorus</li> </ul> </li> <li>• Water clarity               <ul style="list-style-type: none"> <li>o Secchi depth</li> </ul> </li> <li>• Phytoplankton abundance               <ul style="list-style-type: none"> <li>o Chlorophyll a</li> </ul> </li> </ul> |
| Sewage plume mapping                  | <ul style="list-style-type: none"> <li>• Ratio of <math>14^N</math> to <math>15^N</math> (<math>15^N</math>)</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| <i>Lyngbya</i> monitoring             | <ul style="list-style-type: none"> <li>• Presence/absence of <i>Lyngbya</i></li> <li>• Percent cover</li> <li>• Substrate type (seagrass, bare etc)</li> <li>• Biomass</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| Coral monitoring                      | <ul style="list-style-type: none"> <li>• Total percent cover</li> <li>• Incidence of coral bleaching</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| Seagrass depth range and distribution | <ul style="list-style-type: none"> <li>• Difference between the upper and lower depth limit of the seagrass <i>Zostera capricorni</i></li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |

## 8 Estuarine and Marine Wetlands

### 8.5 Marine and Tropical Sciences Research Facility

The Marine and Tropical Sciences Research Facility (MTSRF) is supporting many projects to research the key environmental challenges facing the Great Barrier Reef and its catchments, tropical rainforests, including the Wet Tropics World Heritage Area, and the Torres Strait. Under the program heading 'Halting and reversing the decline of water quality', the project 'Marine and estuarine indicators and thresholds of concern' is investigating indicators of ecosystem health in response to changes in water quality. The estuarine and marine components are being treated separately by different researchers. The project is still in progress, and information is scarce.

The project proposal notes for the estuarine component of the project listed a set of indicators that would be investigated in the project (Table 34). The researchers are also compiling a literature review on estuarine indicators which is due for completion in mid-2007 (R. Connolly, Griffith University pers. comm.).

The marine component of the project is investigating potential water quality specific indicators for monitoring estuaries and inshore coral reefs. Although water quality project is still in progress, an interim list of indicators has been compiled for further investigation (Table 35) (Fabricius et al. 2007). Some have been highlighted as being particularly promising. The specificity of many of these indicators is poorly understood, as most research has been based on field assessments where many of the variables are highly correlated. Testing is currently underway to determine causality and threshold levels. This will enable measures to be combined in a composite indicator system which can distinguish between acute and chronic exposure to stressors.

**Table 34. Estuarine indicators proposed for investigation in the MTSRF project: Marine and estuarine indicators and thresholds of concern.**

| Indicator group | Indicators and measures                                                                                                                                                        |
|-----------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Water Quality   | <ul style="list-style-type: none"><li>• Salinity</li><li>• Nutrients</li><li>• Turbidity</li><li>• Pesticides</li></ul>                                                        |
| Fish            | <ul style="list-style-type: none"><li>• Community analysis</li><li>• Morphometric measures (length, weight, etc)</li><li>• Growth index on juveniles (RNA:DNA ratio)</li></ul> |
| Crabs           | <ul style="list-style-type: none"><li>• Hepato-somatic index on mud crabs and grapsid crabs</li></ul>                                                                          |

**Table 35. Potential water quality indicators for estuaries and inshore coral reefs of the Great Barrier Reef.**

| Indicator group | Measure                                           | Indicator for                                                                                                               |
|-----------------|---------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------|
| Water Quality   | Water column chlorophyll                          | <ul style="list-style-type: none"> <li>Nutrients</li> </ul>                                                                 |
|                 | Suspended solids                                  | <ul style="list-style-type: none"> <li>Resuspension of old seafloor</li> <li>Newly imported sediments</li> </ul>            |
|                 | Dissolved nutrients                               | <ul style="list-style-type: none"> <li>Upwelling</li> <li>Import through rivers</li> </ul>                                  |
|                 | Stable isotopes in DOC and DON                    | <ul style="list-style-type: none"> <li>River imports vs upwelling</li> <li>Plant origin</li> </ul>                          |
| Light           | Light attenuation                                 | <ul style="list-style-type: none"> <li>Turbidity</li> <li>Suspended solids</li> </ul>                                       |
|                 | Secchi disc                                       | <ul style="list-style-type: none"> <li>Turbidity</li> <li>Suspended solids</li> </ul>                                       |
| Reef sediments  | Amount and composition (sediment traps)           | <ul style="list-style-type: none"> <li>Resuspension</li> <li>Newly imported sediments</li> </ul>                            |
|                 | Grain size (sediment surface samples)             | <ul style="list-style-type: none"> <li>Wave exposure</li> <li>Newly imported sediments</li> </ul>                           |
|                 | Colour                                            | <ul style="list-style-type: none"> <li>CaCO<sub>3</sub></li> <li>Organics</li> <li>Terrestrial vs marine sources</li> </ul> |
|                 | Sediment nutrients, organic contents, chlorophyll | <ul style="list-style-type: none"> <li>Organics</li> <li>Terrestrial vs marine sources</li> </ul>                           |
|                 | IPAM, PAM of microphytobenthos communities        | <ul style="list-style-type: none"> <li>Benthic productivity</li> <li>Light</li> <li>Nutrients</li> <li>Others?</li> </ul>   |
| Reef biofilms   | Foraminifera                                      | <ul style="list-style-type: none"> <li>Nutrients</li> <li>Light</li> <li>Organic enrichment</li> <li>Others?</li> </ul>     |
|                 | Diatoms                                           | <ul style="list-style-type: none"> <li>Nutrients</li> <li>Light</li> <li>Others?</li> </ul>                                 |
|                 | Bacteria                                          | <ul style="list-style-type: none"> <li>?</li> </ul>                                                                         |

# 8 Estuarine and Marine Wetlands

**Table 36. Potential indicators for determining coral reef health in the Great Barrier Reef (Sweatman 2007).**

| Indicator Headings                   | Indicators                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|--------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Reef Structure</b>                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| Biodiversity and community structure | <ul style="list-style-type: none"> <li>• Hard coral cover (total)</li> <li>• Hard coral cover (diversity)</li> <li>• Soft coral cover (total)</li> <li>• Macroalgae</li> <li>• Coral fish abundance</li> <li>• Coral fish diversity</li> <li>• Rugosity</li> <li>• Focal species (iconic/long replacement time)</li> <li>• Large <i>Porites</i></li> <li>• Dugong</li> <li>• Turtles</li> <li>• Barramundi cod</li> <li>• Maori wrasse</li> <li>• Sharks</li> <li>• <i>Bolbometopon</i></li> </ul> |
| Abiotic factors                      | <ul style="list-style-type: none"> <li>• Sea surface temperature (SST)</li> <li>• Salinity</li> <li>• Chlorophyll a / Ocean colour</li> <li>• Turbidity</li> <li>• Sedimentation</li> <li>• Pesticides</li> <li>• Year of last cyclone</li> </ul>                                                                                                                                                                                                                                                  |
| Habitat extent                       | <ul style="list-style-type: none"> <li>• Area of coral reef</li> <li>• Area of mangroves</li> <li>• Seagrass (extent and density)</li> </ul>                                                                                                                                                                                                                                                                                                                                                       |
| <b>Reef Function</b>                 |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| Reproduction/recruitment             | <ul style="list-style-type: none"> <li>• Coral size frequency (inshore to genus, 5 size categories)</li> <li>• Coral settlement</li> <li>• Coral recruitment (juveniles)</li> <li>• Fish size frequency</li> <li>• Fish recruitment</li> </ul>                                                                                                                                                                                                                                                     |

| Indicator Headings            | Indicators                                                                                                                                                                                                                                                                                                                                                                                                   |
|-------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Coral mortality               | <ul style="list-style-type: none"> <li>• Recent partial mortality (esp massives)</li> <li>• Coral disease prevalence</li> <li>• Bleaching prevalence</li> <li>• Time since last bleaching</li> <li>• Crown-of-thorns starfish (COTS)</li> <li>• COTS outbreak status</li> <li>• Time since COTS outbreak</li> </ul>                                                                                          |
| Herbivory                     | <ul style="list-style-type: none"> <li>• Herbivorous fish abundance and composition</li> </ul>                                                                                                                                                                                                                                                                                                               |
| <b>Interactions and Risk</b>  |                                                                                                                                                                                                                                                                                                                                                                                                              |
| Tourism/coastal development   | <ul style="list-style-type: none"> <li>• Human sewage biomarkers</li> <li>• Coral damage index e.g. ship grounding, anchor damage</li> <li>• Tourism index (EMC)</li> <li>• Coastal development index (remote sensing, population, marina approvals)</li> <li>• Recreation (boat registrations, diver days)</li> </ul>                                                                                       |
| Agriculture and inland runoff | <ul style="list-style-type: none"> <li>• Pollutant accumulation (passive sampling, estuarine fish biomarkers)</li> <li>• Coral physiological indicators (e.g. coral colour)</li> <li>• Modified FORAM index (nutrient loading)</li> <li>• Land use change (clearing, fertiliser and pesticide use, wetland areas)</li> </ul>                                                                                 |
| Fishing                       | <ul style="list-style-type: none"> <li>• Abundance and size of targeted finfish species (incl harvest spp)</li> <li>• Red throat emperor density and biomass</li> <li>• Trochus</li> <li>• Beche-de-mer</li> <li>• Tropical rock lobster</li> <li>• Number of recreational fishers</li> <li>• Catch and effort (incl trawl and recreational)</li> <li>• Spawning aggregations</li> <li>• By-catch</li> </ul> |
| Indigenous use                | <ul style="list-style-type: none"> <li>• Number of indigenous agreements/TUMRAs</li> </ul>                                                                                                                                                                                                                                                                                                                   |
| Climate change                | <ul style="list-style-type: none"> <li>• GBRMPA Reef Temp heat stress predictions</li> <li>• Bleaching surveys</li> </ul>                                                                                                                                                                                                                                                                                    |
| Introduced marine pests       | <ul style="list-style-type: none"> <li>• Distribution, abundance and risk</li> </ul>                                                                                                                                                                                                                                                                                                                         |

# 8 Estuarine and Marine Wetlands

**Table 37. Key indicators identified by the Mesoamerican Indicator Framework for assessing the health of Central American reefs.**

| Indicator Headings                 | Indicators                                                                                                                                                                                                         |
|------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>I. Reef Ecosystem Structure</b> |                                                                                                                                                                                                                    |
| Biodiversity                       | <ul style="list-style-type: none"> <li>• Biodiversity</li> <li>• Fish diversity</li> <li>• Focal species (threatened and endangered species)</li> </ul>                                                            |
| Community structure                | <ul style="list-style-type: none"> <li>• Coral cover</li> <li>• Coral:algal cover</li> <li>• Fish abundance</li> <li>• Rugosity</li> </ul>                                                                         |
| Abiotic factors                    | <ul style="list-style-type: none"> <li>• Water quality (temperature, salinity, transparency)</li> <li>• Ocean colour</li> <li>• Sedimentation rates</li> </ul>                                                     |
| Habitat extent                     | <ul style="list-style-type: none"> <li>• Coral reef extent</li> <li>• Mangrove extent</li> <li>• Seagrass extent</li> </ul>                                                                                        |
| <b>II. Reef Ecosystem Function</b> |                                                                                                                                                                                                                    |
| Reproduction/recruitment           | <ul style="list-style-type: none"> <li>• Coral recruitment</li> <li>• Coral size frequency</li> <li>• Fish recruitment</li> <li>• Fish size frequency</li> </ul>                                                   |
| Coral condition                    | <ul style="list-style-type: none"> <li>• Coral mortality</li> <li>• Coral disease prevalence</li> <li>• Coral bleaching prevalence</li> </ul>                                                                      |
| Reef accretion bioerosion          | <ul style="list-style-type: none"> <li>• Coral growth</li> <li>• Number of bioeroders on corals</li> <li>• Net reef accretion</li> </ul>                                                                           |
| Herbivory                          | <ul style="list-style-type: none"> <li>• Herbivorous fish abundance</li> <li>• <i>Diadema</i> abundance</li> <li>• Fleshy macroalgal index</li> <li>• Fish bite rates</li> <li>• Green turtle abundance</li> </ul> |

| Indicator Headings                                                | Indicators                                                                                                                                                                                             |
|-------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>III. Threats/Drivers of Change (natural and anthropogenic)</b> |                                                                                                                                                                                                        |
| Tourism/coastal development                                       | <ul style="list-style-type: none"> <li>• Human sewage biomarkers</li> <li>• Tourism index</li> <li>• Coastal development index</li> <li>• Land-use change footprint</li> </ul>                         |
| Agriculture and inland runoff                                     | <ul style="list-style-type: none"> <li>• Contaminant accumulation (sediment and biota)</li> <li>• Molecular biomarkers of pollutants</li> <li>• FORAM index (nutrient loading)</li> </ul>              |
| Overfishing                                                       | <ul style="list-style-type: none"> <li>• Fish density and size</li> <li>• Conch/lobster abundance</li> <li>• Spawning aggregations</li> <li>• % fishers with alternative livelihood options</li> </ul> |
| Global climate change                                             | <ul style="list-style-type: none"> <li>• Biomarkers of stress</li> <li>• FORAM index of UV stress</li> <li>• Coral bleaching index</li> <li>• Bleaching resistance/resilience ranking</li> </ul>       |
| <b>IV. Social well-being</b>                                      |                                                                                                                                                                                                        |
| Human health                                                      | <ul style="list-style-type: none"> <li>• Contaminant accumulation (human breast milk)</li> <li>• Cholera</li> <li>• Safe water/sanitation</li> <li>• Reproductive health index</li> </ul>              |
| Economic                                                          | <ul style="list-style-type: none"> <li>• Stratification of wealth</li> <li>• Adjusted net savings</li> <li>• % income from reef</li> <li>• Environmental sustainability index (ESI)</li> </ul>         |
| Cultural integrity                                                | <ul style="list-style-type: none"> <li>• # ethno-languages</li> <li>• Net in/out migration</li> <li>• Gender and cultural equality</li> <li>• Human development index</li> </ul>                       |
| Policy and law                                                    | <ul style="list-style-type: none"> <li>• Area under protection</li> <li>• MPA effectiveness ratings</li> <li>• World Bank governance indicators</li> </ul>                                             |

continued on next page

## 8 Estuarine and Marine Wetlands

Table 37 continued from previous page

| Indicator group         | Measure                                                              | Indicator for                                                                                                                        |
|-------------------------|----------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------|
| Barramundi in estuaries | EROD                                                                 | <ul style="list-style-type: none"> <li>• PAHs</li> <li>• PCBs</li> <li>• Dioxins</li> </ul>                                          |
|                         | DNA damage                                                           | Several stressors                                                                                                                    |
|                         | RNA-DNA ratio                                                        | Multiple stressors                                                                                                                   |
|                         | AchE                                                                 | <ul style="list-style-type: none"> <li>• Organophosphorus</li> <li>• Carbamate insecticides</li> </ul>                               |
|                         | Fluorescent aromatic compounds                                       | <ul style="list-style-type: none"> <li>• Metabolites of PAHs</li> </ul>                                                              |
|                         | Condition factor                                                     | <ul style="list-style-type: none"> <li>• Stress</li> <li>• Fitness</li> </ul>                                                        |
| Coral physiology        | RNA/DNA                                                              | <ul style="list-style-type: none"> <li>• Light</li> <li>• Others?</li> </ul>                                                         |
|                         | Tissue thickness                                                     | <ul style="list-style-type: none"> <li>• Light</li> <li>• Nutrients</li> <li>• Others?</li> </ul>                                    |
|                         | Coral colour                                                         | <ul style="list-style-type: none"> <li>• Light</li> <li>• Nutrients</li> <li>• Other stress conditions (e.g. temperature)</li> </ul> |
|                         | IPAM or PAM, zooxanthellae density, tissue chlorophyll concentration | <ul style="list-style-type: none"> <li>• Light</li> <li>• Nutrients</li> <li>• Other stress conditions</li> </ul>                    |
|                         | Bumpiness in massive <i>Porites</i>                                  | <ul style="list-style-type: none"> <li>• Sedimentation</li> <li>• Disturbance</li> <li>• Light</li> <li>• Others?</li> </ul>         |
| Reef communities        | Macro-bioeroders in <i>Porites</i>                                   | <ul style="list-style-type: none"> <li>• Particulate nutrients</li> <li>• Others?</li> </ul>                                         |
|                         | Lower depth limit of reef development                                | <ul style="list-style-type: none"> <li>• Light</li> <li>• Sedimentation</li> </ul>                                                   |

| Indicator group | Measure                                                   | Indicator for                                                                                                                                                         |
|-----------------|-----------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                 | Hard coral richness                                       | <ul style="list-style-type: none"> <li>• Light</li> <li>• Sedimentation</li> <li>• Organic enrichment</li> <li>• Others?</li> </ul>                                   |
|                 | Octocoral richness                                        | <ul style="list-style-type: none"> <li>• Suspended solids</li> <li>• Water clarity</li> </ul>                                                                         |
|                 | Density and species richness of coral recruits            | <ul style="list-style-type: none"> <li>• Sedimentation</li> <li>• Nutrients</li> <li>• Light</li> <li>• Organic enrichment</li> </ul>                                 |
|                 | Macroalgal biomass/cover, split by major taxonomic groups | <ul style="list-style-type: none"> <li>• Nutrients</li> <li>• Waves</li> <li>• Herbivory</li> <li>• Space availability</li> <li>• Light</li> <li>• Others?</li> </ul> |
|                 | Macroalgal community composition                          | <ul style="list-style-type: none"> <li>• Nutrients</li> <li>• Waves</li> <li>• Herbivory</li> <li>• Space availability</li> <li>• Light</li> <li>• Other?</li> </ul>  |
|                 | Fish abundances (esp. herbivores)                         | <ul style="list-style-type: none"> <li>• Turbidity</li> <li>• Substratum structure</li> <li>• Others?</li> </ul>                                                      |

Indicators of reef health are being investigated under the same MTSRF project. A draft report has been produced which provides a list of potential indicators for coral reef health on the Great Barrier Reef (Table 36) (Sweatman 2007). Data for the majority of the proposed indicators can be sourced from existing databases. The indicators were selected at a workshop for scientists and managers at AIMS based on the MesoAmerican (MAR) Reef Initiative program, an international, multi-institutional effort to track the health of reefs off the coast of Mexico, Belize and

Honduras. A major component of the MAR program is to develop a set of ecological and socio-economic indicators to provide a consistent evaluation and reporting of reef health and quality of life (Table 37) (Health Reefs for Healthy People: Key Indicators – webpage accessed 15/5/2007).

# 8 Estuarine and Marine Wetlands

## 8.6 Coastal CRC

The Coastal CRC produced many products, many of which are still available on the website. The work that informed the Matters for Target review of Estuarine, coastal and marine habitat indicators (from Scheltinga et al. 2004) can be found on the Ozcoasts website, as can a series of estuarine conceptual models. A major project reported on the assessment of historical changes in coastal environments (Duke et al. 2003; Schaffelke et al. 2005). It has allowed planners to assess impacts from current and proposed activities by providing a benchmark of changed based on community perspectives, coastal features, natural habitats, estuarine fisheries, fish communities and vegetated tidal habitats. A list of tidal wetland indicators (field and remote sensing) was proposed (Table 38). Although the indicators are not strictly indicators of condition, they can assist in pinpointing changes that have occurred in the past caused by anthropogenic impacts.

As can be seen in Table 38, many changes manifest in only a handful of impacts e.g. dieback or loss of vegetation can be the result of zonal shifts, storm damage, wrack accumulation, spill damage, and direct damage, to name a few. In order to assist operators to correctly match the impact with the cause, Duke et al. (2003) also developed two keys (ground and remote sensing) (Table 39).

**Table 38. Proposed categories of tidal wetland change and indicators for assessing coastal and estuarine habitat (from Duke et al. 2003, Schaffelke et al. 2005).**

| Type of Change                                                                                                                                                          | Wetland Indicator Tool                                                                                                                                                                                                                                    | Driver of Change                                                                         |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------|
| <b>A. Direct – Intended and obviously human related</b>                                                                                                                 |                                                                                                                                                                                                                                                           |                                                                                          |
| <b>1. Reclamation loss.</b> Replacement with structures and/or sites – ports, industrial, urban, canals.                                                                | <b>Ground:</b> Reported reclamation, constructed sea and canal walls.<br><b>Remote:</b> Geometric loss patterns in maps and photos.                                                                                                                       | Port, industry and urban development.                                                    |
| <b>2. Direct damage.</b> Dieback/ damage/loss caused by cutting, root exposure, sediment disturbance, root burial, ponded pastures and agricultural encroachment.       | <b>Ground:</b> Cut stumps, paths, vehicle tracks, exposed or buried roots, trampled substrate, compacted soil, structures blocking tidal exchange, dead/sick trees.<br><b>Remote:</b> Dieback/loss radiating from access points and near retaining walls. | Access to, construction of retaining walls for ponded pastures and tide blocking drains. |
| <b>B. Direct – Unintended and obviously human related</b>                                                                                                               |                                                                                                                                                                                                                                                           |                                                                                          |
| <b>3. Restricted tidal exchange.</b> Dieback/damage associated with construction and development projects often resulting in impoundment inundation of breathing roots. | <b>Ground:</b> Pooled low tide water, restricted water flow, delayed tidal exchange, stagnant water, dead/ damaged trees.<br><b>Remote:</b> Dieback/loss near reclamation and constructed levees and banks.                                               | Constructions, like roads and seawalls, altering water flow and tidal exchange.          |

| Type of Change                                                                                                                                             | Wetland Indicator Tool                                                                                                                                                                                                              | Driver of Change                                                                                     |
|------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------|
| <b>4. Spill damage.</b> Dieback/damage following incidents/accidents involving spills of toxic chemicals which smother breathing surfaces                  | <b>Ground:</b> Reported spill incident, black tidal rings around stems, chemical (oil) in sediments, oily smell, dead/sick trees.<br><br><b>Remote:</b> Dieback/loss along tidal contours.                                          | Spillage of toxic chemicals, oil spills.                                                             |
| <b>C. Indirect – Unintended and less obviously human related</b>                                                                                           |                                                                                                                                                                                                                                     |                                                                                                      |
| <b>5. Depositional gains and losses</b> e.g. at estuary mouths and areas behind groins and training walls, dieback/damage associated with sediment burial. | <b>Ground:</b> Colonisation downstream on banks, dieback with stream edge erosion or deposition.<br><br><b>Remote:</b> 'Island' appearances, plus edge gains and losses along water margins near mouth and along sand/beach ridges. | Catchment vegetation clearing, soil disturbance, and construction of river/shoreline training walls. |
| <b>6. Nutrient excess.</b> Dieback/damage associated with excess algal growth on breathing roots.                                                          | <b>Ground:</b> Nutrients in water and sediment, foliage uptake of nitrogen, increased plant growth, excess macroalgae on exposed roots, pooled low tide water, dead/sick trees.<br><br><b>Remote:</b> Loss of inner stands.         | Inputs of fertiliser and sewage.                                                                     |
| <b>7. Species-specific effect.</b> Dieback/damage of species sensitive to toxic chemicals.                                                                 | <b>Ground:</b> Toxic chemicals (herbicide) in water and sediment, epicormic sprouting, dead/sick trees.<br><br><b>Remote:</b> Affects only select species.                                                                          | Inputs of toxic chemicals e.g. in catchment runoff.                                                  |
| <b>D. Not obviously human related</b>                                                                                                                      |                                                                                                                                                                                                                                     |                                                                                                      |
| <b>8. Wrack accumulation.</b> Dieback/damage associated with build-up of beach wrack on breathing roots and localised impoundment.                         | <b>Ground:</b> Wrack of dead algae (e.g. Lyngbya) or seagrass on roots, blocked tidal exchange, pooled water, dead/sick trees<br><br><b>Remote:</b> Dieback/loss patches in beach and exposed stands.                               | Post-storm and algal blooms debris accumulation, possibly associated with poor water quality.        |
| <b>9. Herbivore/insect attack.</b> Dieback/damage associated with excessive herbivore/insect attacks on foliage or tree stems.                             | <b>Ground:</b> Defoliated trees, insect frass on forest floor, insect presence, dead/sick trees.<br><br><b>Remote:</b> Patches of low density canopy foliage and dieback/loss.                                                      | Effects on herbivore/insect, possibly associated with stressed habitat.                              |
| <b>10. Storm damage.</b> Dieback/damage associated with severe storm activity and incidents.                                                               | <b>Ground:</b> Reported storm, damaged bark and foliage, exposed roots, broken stems, up rooted trees, sheltered survivors, dead/sick trees.<br><br><b>Remote:</b> Dieback/loss in patches or gaps.                                 | Severe storms, cyclonic winds, strong wave activity, high stream flows, lightning.                   |

## 8 Estuarine and Marine Wetlands

Table 38 continued from previous page

| Type of Change                                                                                                                 | Wetland Indicator Tool                                                                                                                                                                                                      | Driver of Change                                                   |
|--------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------|
| <b>11. Ecotone shift.</b> Dieback/damage associated with climate change – shifts within the tidal zone.                        | <b>Ground:</b> Bands of dieback within mangrove zone, along saltpans, recruitment into saltpans.<br><b>Remote:</b> Dieback/loss and gains along tidal contours in tidal zone.                                               | Climate (rainfall) change affected by local and/or global factors. |
| <b>12. Zonal shift.</b> Dieback/damage associated with sea level change in the entire tidal wetland (mangrove/saltmarsh) zone. | <b>Ground:</b> Reported sea level change – landward: mangrove recruitment and terrestrial dieback; seaward: eroded trees and losses<br><b>Remote:</b> Dieback/loss and gains at seaward and landward margins of tidal zone. | Sea level change affected by local and/or global factors.          |

Table 39. Keys to assist identification of types of change in tidal wetland habitats (Duke et al. 2003).

|                                                                                                                                                        |                                    |
|--------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------|
| <b>Key based on ground observations</b>                                                                                                                |                                    |
| 1. Loss of trees due to obvious human activities – construction, cutting, access ways .....                                                            | go to 2                            |
| 1. Dead, sick trees not obviously affected by people.....                                                                                              | go to 3                            |
| 2. Cut tree stems, roads, tracks, trampling .....                                                                                                      | (2) <b>Direct Damage</b>           |
| 2. Constructed sea walls, landfill, channelled drainage .....                                                                                          | (1) <b>Reclamation Loss</b>        |
| 3. Extraneous material present .....                                                                                                                   | go to 4                            |
| 3. No extraneous material present .....                                                                                                                | go to 6                            |
| 4. Oil slick marks as rings around tree stems and above-ground roots, plus residual oil in sediment, oil sheen in footprints and on surface water..... | (4) <b>Spill Damage</b>            |
| 4. Plant matter covering above-ground roots, associated with dieback.....                                                                              | go to 5                            |
| 5. Wrack (e.g. seagrass, <i>Lyngbya</i> ) present, associated with impoundment .....                                                                   | (8) <b>Wrack Accumulation</b>      |
| 5. Macroalgae present on sediment and covering above-ground roots .....                                                                                | (6) <b>Nutrient Excess</b>         |
| 6. Abnormal appearance of trees, tree parts, and dieback .....                                                                                         | go to 7                            |
| 6. Trees with normal appearance and dieback .....                                                                                                      | go to 9                            |
| 7. Epicormic sprouts, species-specific dieback (notably <i>Avicennia</i> sp.), growth deformities (e.g. with <i>Avicennia</i> pneumatophores).....     | (7) <b>Species-specific Effect</b> |
| 7. Notable damage effects in canopy foliage, branches, stems on the ground .....                                                                       | go to 8                            |
| 8. Defoliated canopy, leaf feeding scars, obvious frass on forest floor .....                                                                          | (9) <b>Herbivore/Insect Attack</b> |
| 8. Damaged bark, broken limbs, scars & damage on 'weather' side of trees.....                                                                          | (10) <b>Storm Damage</b>           |

- 9. Recruitment, new stands, encroachment landward or seaward, associated with dieback.....go to 10
- 9. Little or no recruitment, associated construction works.....**(3) Restricted Tidal Exchange**
- 10. Orientated along upstream-downstream gradient, estuary tributaries and river mouths .....**(5) Depositional Gains and Losses**
- 10. Orientated along tidal contours, parallel to land and sea margins .....go to 11
- 11. Associated with mangrove to salt marsh-saltpan ecotone.....**(11) Ecotone Shift**
- 11. Associated with mangrove-seawater plus mangrove-terrestrial zone edges..... **(12) Zonal Shift**

#### Key based on remote sensing observations

- 1. Gains shown as patches of small, densely packed trees .....go to 2
- 1. Dieback of trees or patches of trees, plus stands with low density canopies .....go to 3
- 2. Gains along the waters' edge, sometimes as 'islands' .....**(5) Depositional Gains and Losses**
- 2. Gains landward (as encroachment) and losses seaward, or vice versa ..... **(12) Zonal Shift**
- 3. Partial canopy loss of individual trees, low canopy density .....**(9) Herbivore/Insect Attack**, or **(4) Spill Damage** (sublethal effect)
- 3. Complete canopy loss of individual trees (dieback death) .....go to 4
- 4. Individual trees, 'freckled' effect (dead *Avicennia* sp.).....**(7) Species-specific Effect**
- 4. Whole stands, or clusters of trees.....go to 5
- 5. Geometric boundaries, straight lines.....go to 6
- 5. No geometric patterns .....go to 8
- 6. Entire area and boundaries with geometric patterns ..... **(1) Reclamation Loss**
- 6. Some boundaries not geometric, nearby geometric.....go to 7
- 7. Areas cut-off from sea/water edge .....**(3) Restricted Tidal Exchange**
- 7. Areas with access points, roads, paths ..... **(2) Direct Damage**
- 8. Non-defined patches of dead trees.....go to 9
- 8. Dead trees along apparent contours, curvi-linear pattern .....go to 11
- 9. Associated with beach ridges, and in exposed stands.....**(8) Wrack Accumulation**
- 9. Dead trees in patches, usual interior stands .....go to 10
- 10. Blown over trees, directional effect..... **(10) Storm Damage**
- 10. Dead trees standing, no fresh broken stems, patches associated with inner areas, near salt pans..... **(6) Nutrient Excess**
- 11. Changes associated with mangrove-saltpan ecotone.....**(11) Ecotone Shift**
- 11. Patches usually follow inner stand contours .....**(4) Spill Damage** (lethal effect)

# 8 Estuarine and Marine Wetlands

## 8.7 Seagrass Watch

Seagrass-Watch is a community assessment and monitoring program which aims to raise awareness on the condition and trend of nearshore seagrass ecosystems and provide an early warning of major coastal environment changes. The program commenced in Australia in 1998 and has expanded internationally to over 165 sites in 18 countries. Communities regularly monitor sites, collecting data on seagrass condition, extent and distribution (Table 40).

## 8.8 AquaBAMM

In conjunction with the development of freshwater riverine and non-riverine AquaBAMM indicators, a set of estuarine indicators has been proposed. As trialling has yet to occur, they are not ready for release. The first trials will occur in Southeast Queensland, beginning mid-2007.

**Table 40. Measures collected by community groups in Seagrass-Watch (McKenzie et al. 2003).**

| Program                                                                                                                       | Measures                                                                                                                                                                                                                                                                                                                        |
|-------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Mapping                                                                                                                       | <ul style="list-style-type: none"><li>• Location of inner and outer edges of meadows</li></ul>                                                                                                                                                                                                                                  |
| Monitoring                                                                                                                    | <ul style="list-style-type: none"><li>• Photographic record</li><li>• Sediment composition</li><li>• Seagrass % cover</li><li>• Seagrass % composition</li><li>• Canopy height</li><li>• Algae % cover</li><li>• Epiphyte % cover</li><li>• Seagrass identification</li><li>• Depth</li><li>• Extent and distribution</li></ul> |
| Condition and resilience (requires expert assistance therefore specimens are collected for further treatment by laboratories) | <ul style="list-style-type: none"><li>• Seed reserves</li><li>• Carbohydrate reserves</li><li>• Amino acid composition</li><li>• Photosynthesis capability</li><li>• Seed viability</li><li>• Ratio of <math>^{14}\text{N}</math> to <math>^{15}\text{N}</math> (<math>\delta^{15}\text{N}</math>) (sewage impact)</li></ul>    |

# 9 Lacustrine and Palustrine Wetlands

# 9

Lacustrine wetlands e.g. lakes, are broadly described as being situated in a topographic depression or a dammed river channel, having sparse vegetation coverage (less than 30 percent of their coverage area is made up of vegetation such as trees, shrubs or persistent emergent vegetation), and the total area exceeds 8 ha. Similar habitats less than 8 ha are also included if active wave-formed or bedrock shoreline features makes up all or part of the boundary, or their depth is greater than 2 m (Cowardin et al. 1979). Ocean-derived salinity is always less than 0.5%.

Palustrine wetlands, typically described as swamps, bogs, marshes and prairies, are dominated by trees, shrubs, persistent emergents, emergent mosses, and lichens, and the waters contain less than 0.5% of ocean-derived salts. Palustrine wetlands may include wetlands lacking vegetation if that wetland has the following characteristics: active waves are formed or bedrock features are lacking, water depth in the deepest part of the basin is less than 2 m at low water, and salinity is still less than 0.5% from ocean-derived salts.

The EPA published a series of Management Profiles for major wetland types found in Queensland. They are available for download from the EPA website:

[http://www.epa.qld.gov.au/nature\\_conservation/habitats/wetlands/wetland\\_management\\_profiles/](http://www.epa.qld.gov.au/nature_conservation/habitats/wetlands/wetland_management_profiles/).

## 9.1 Natural Resource Management (NRM) Resource Condition Indicators

Under the NRM Monitoring and Evaluation Framework (NM&EF), wetlands are identified as those bodies of water that are generally characterised as being lacustrine or palustrine in the literature i.e. lakes (lacustrine) and swamps, marshes, bogs (palustrine). The current wetland NRM resource condition indicators are listed under the Inland Aquatic Ecosystems Integrity Matter for Target (Wetland ecosystem extent and distribution and Wetland ecosystem condition) (Table 41). These indicators are currently undergoing review by the NLWRA as part of a system-wide review in preparation for the second Audit.

**Table 41. Current recommended indicators for wetland (lacustrine and palustrine) Matter for Target.**

| Indicator Heading                                          | Recommended Indicators                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Wetland ecosystem extent and distribution                  | Extent of regionally significant wetlands (Indicator Status: Unclear)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Wetland ecosystem condition (Indicator Status: For Advice) | <p>Condition of regionally significant wetlands based on:</p> <ul style="list-style-type: none"> <li>• <b>Colour</b> (Indicator Status: For Advice)</li> <li>• <b>Dissolved oxygen and temperature</b> (Indicator Status: For Advice)</li> <li>• <b>Extent of inundation</b> (Indicator Status: For Advice)</li> <li>• <b>Macroinvertebrate diversity and community composition</b> (Indicator Status: For Advice)</li> <li>• <b>Macroinvertebrate index</b> (Indicator Status: For Advice)</li> <li>• <b>Macroinvertebrate indicator species</b> (Indicator Status: For Advice)</li> <li>• <b>Nutrients (Phosphorus and Nitrogen)</b> (Indicator Status: For Advice)</li> <li>• <b>Transparency</b> (Indicator Status: For Advice)</li> <li>• <b>Vegetation</b> (Indicator Status: For Advice)</li> <li>• <b>Phytoplankton</b> (Indicator Status: For Advice)</li> </ul> |

# 9 Lacustrine and Palustrine Wetlands

A project to review the wetland indicators (National Wetland Indicators Project) (Conrick et al. 2007) commenced in late 2006 and has been advised by the findings of this project, particularly the development of conceptual models (Section 9.4, below) and the wetland description tool (Section 4.3). The review has aligned with the concurrent development of a National Water Commission – Australian Water Resources 2005 project entitled 'A Framework for the Assessment of River and Wetland Health' (FARWH) which will provide methods for comparing and integrating existing river and wetland health outputs to facilitate national reporting from comparable state, territory, and regional NRM assessments e.g. the MDBC's Sustainable Rivers Audit, Victoria's Index of Stream Condition, Tasmania's CFEV project, and eventually Queensland's SEAP program.

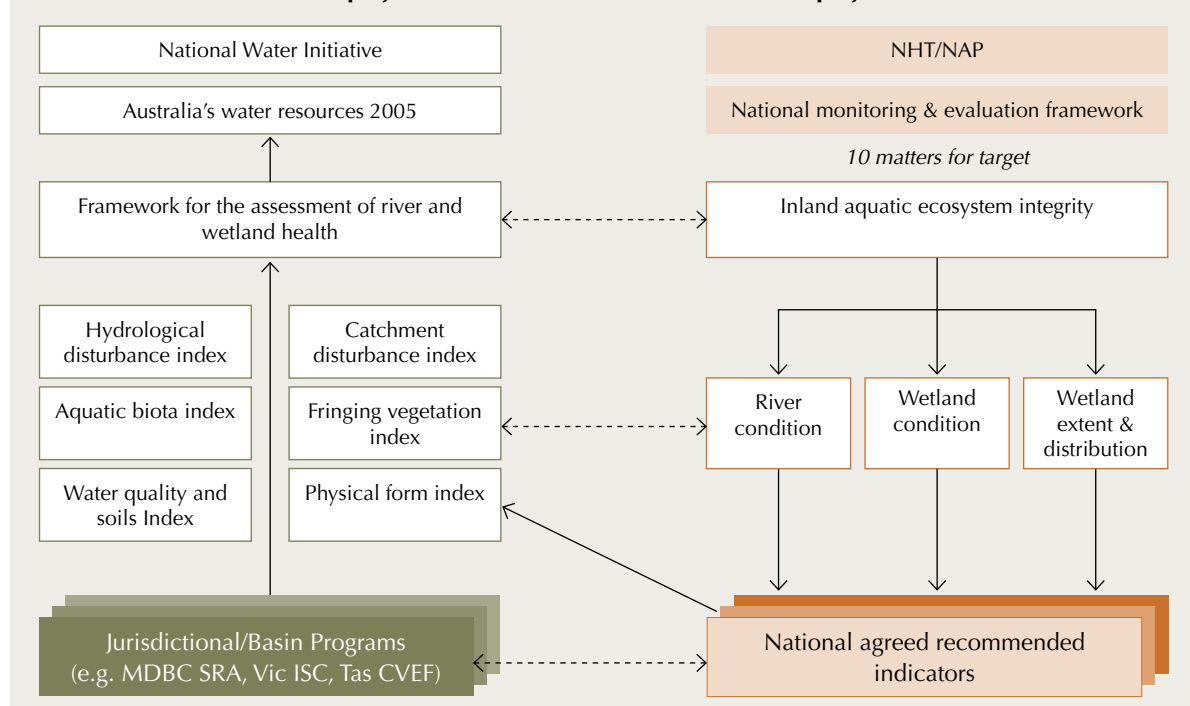
FARWH is based on the premise that ecological integrity is the fundamental measure of river and wetland health and, although the ultimate measure of that integrity is damage to the biota, other components of the ecosystem are just as important, and should be included in an assessment of ecosystem health. It recommends selecting indicators under six themes although the selection of specific indicators is left to

the discretion of the investigator. A referential approach will be used to assess each indicator and the resulting indices will be aggregated and integrated to generate scores which can be reported and compared at the state and/or national level (Norris et al. 2007).

There were significant efficiencies to be made by the National Wetland Indicators Project in developing the wetland themes and indicators proposed by the FARWH and providing this information to the FARWH team for inclusion in their framework. The manner in which the two programs are structured, and how they propose to work together is shown in Figure 6 (Conrick et al. 2007).

A national workshop for the National Wetlands Indicator Project elected to retain the six themes as proposed in the FARWH (catchment disturbance, physical form, hydrological disturbance, water quality and soils, fringing zone, and aquatic biota) but also determined that, in order to be appropriate for wetlands, they needed slight modification. Consequently, the National Wetlands Indicator Project is recommending that the six wetland themes for the NM&EF Matter for Target will be catchment disturbance, physical form and processes, hydrological disturbance, water and soil quality, fringing zone, and biota (Conrick et al. 2007).

**Figure 6. Relationship between the Australian Water Resources 2005 – Framework for the Assessment of River and Wetland Health project and the National Wetland Indicators project.**



**Table 42. Proposed wetland NRM resource condition indicators.**

| Indicator                                                                                                                                                                                                                                                                                                                                                   | Measures and Methods                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Extent and distribution</b>                                                                                                                                                                                                                                                                                                                              |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| Extent and distribution of wetlands                                                                                                                                                                                                                                                                                                                         | Reference: EPA (2005) Qld Mapping and Classification                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| Extent and distribution of significant wetlands (Ramsar, DIWA, other policy or legal instruments)                                                                                                                                                                                                                                                           | Reference: EPA (2005) Qld Mapping and Classification                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| <b>Condition</b>                                                                                                                                                                                                                                                                                                                                            |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| <b>Catchment disturbance</b><br>incorporates the effects of land use, change in vegetation cover and infrastructure (e.g. roads, rail-lines, water regulation, drainage changes) on the likely run-off of water, sediments, nutrients and other contaminants to wetlands. The index should incorporate the effects of large-scale non-point source impacts. |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| Catchment disturbance                                                                                                                                                                                                                                                                                                                                       | <ul style="list-style-type: none"> <li>• Land use</li> <li>• Infrastructure</li> <li>• Land cover change</li> </ul> Reference: Methods and recommended datasets from: <ul style="list-style-type: none"> <li>o NLWRA (2002) Australian Catchment, River and Estuary Assessment 2002 Vol 1. NLWRA, Canberra. pp 69-77</li> <li>o WRON (2006) Australian Water Resources 2005. Discovery phase. Appendix D: River health. NWC, Canberra. pp 35-41</li> </ul> Datasets include topographic maps, Land use of Australia, version 2 (NLWRA), Catchment scale land use for Australia, Wild Rivers, and the National land use mapping project. |
| <b>Physical form and processes</b><br>uses measures of local topography, physical structure and connectedness (dam, weirs, levee banks, groundwater abstraction) to assess the state of local habitat and its likely ability to support aquatic life. This theme concentrates on the immediate surrounds of the wetland and inside the individual wetland.  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| Area of wetland                                                                                                                                                                                                                                                                                                                                             | <ul style="list-style-type: none"> <li>• Percentage reduction in wetland area</li> </ul> Reference: DSE (2007) Index of Wetland Condition. Methods Manual (draft) <ul style="list-style-type: none"> <li>• Loss in area of original wetland</li> </ul> Reference: Clarkson et al. 2004. Handbook for monitoring wetland condition (NZ wetlands)                                                                                                                                                                                                                                                                                         |

# 9 Lacustrine and Palustrine Wetlands

| Indicator                                                                                                                                                                                                                                                                                                                                                                                                                | Measures and Methods                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Wetland topography                                                                                                                                                                                                                                                                                                                                                                                                       | <ul style="list-style-type: none"> <li>Percentage of wetland where activities (excavation and landforming) have resulted in a change in bathymetry</li> </ul> <p>Reference: DSE (2007) Index of Wetland Condition. Methods Manual (draft).</p> <ul style="list-style-type: none"> <li>'tick and flick' in the field</li> <li>Bathymetric survey (e.g. Robertson &amp; Massenbauer 2005)</li> <li>LIDAR</li> </ul> <p>(Also refer to current indicator: Extent of inundation)</p> <ul style="list-style-type: none"> <li>Degree of sedimentation/erosion</li> </ul> <p>Reference: Clarkson et al. 2004. Handbook for monitoring wetland condition (NZ wetlands)</p> <ul style="list-style-type: none"> <li>Percentage change in bathymetry</li> </ul> <p>Reference: No methods sourced – ? Robertson &amp; Massenbauer 2005</p> |
| Soil disturbance                                                                                                                                                                                                                                                                                                                                                                                                         | <ul style="list-style-type: none"> <li>Percentage and severity of wetland soil disturbance e.g. pugging, driving of vehicles in wetlands, carp muddling, human trampling</li> </ul> <p>Reference: DSE (2007) Index of Wetland Condition. Methods Manual (draft)</p> <ul style="list-style-type: none"> <li>Substrate disturbance – observation of disturbance (none to recently occurred)</li> </ul> <p>Reference: Fennessy et al. (2004) Review of rapid methods for assessing wetland condition. EPA/620/R-04/009. USEPA</p>                                                                                                                                                                                                                                                                                                 |
| <b>Hydrological Disturbance</b><br><p>Both surface water and groundwater regimes are important to aquatic ecosystem function. This theme relies heavily on the premise by Boulton and Brock (1999) that the primary components of the water regime are 'timing, frequency, duration, extent and depth, and variability' and that they are all scale-dependant and are spatially and temporally related to each other</p> |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| Physical modifications to hydrology in-flow, drainage and extraction                                                                                                                                                                                                                                                                                                                                                     | <ul style="list-style-type: none"> <li>Severity of activities that change the water regime</li> </ul> <p>Reference: DSE (2007) Index of Wetland Condition. Methods Manual (draft)</p> <ul style="list-style-type: none"> <li>Impact of man-made structures</li> </ul> <p>Reference: Clarkson et al. 2004. Handbook for monitoring wetland condition (NZ wetlands)</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| Changes to water regime                                                                                                                                                                                                                                                                                                                                                                                                  | REQUIRES MORE DEVELOPMENT AND EXPERT ADVICE                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |

| Indicator                                                                                                                                                                                   | Measures and Methods                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Water And Soil Quality</b><br>Water and soils quality considers the effects on biota of changes in water and soil quality characteristics                                                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| Turbidity (light climate) regime<br>Salinity regime<br>Change in pH<br>Soil properties – change in salinity, acidity                                                                        | REQUIRES MORE DEVELOPMENT AND EXPERT ADVICE<br>Use trials to collect diurnal data<br><ul style="list-style-type: none"> <li>•</li> <li>•</li> <li>•</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| <b>Fringing Zone</b><br>represents structural and condition features of the zone surrounding a wetland.                                                                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| Change in fringing zone (measured by change in vegetation condition)                                                                                                                        | <ul style="list-style-type: none"> <li>• presence of an intact fringing zone</li> <li>• percentage of the fringing zone that is intact</li> <li>• percentage of natural and exotic vegetation</li> </ul> References:<br>1. Spencer et al. (1998) Rapid appraisal wetland condition index.<br><ul style="list-style-type: none"> <li>• Continuity of fringing vegetation – estimated by eye for each of the main vegetation layers (incl trees, rushes/sedges, grasses)</li> <li>• Width of fringing vegetation strip – visual estimates at the four major compass points of a wetland</li> </ul> 2. DSE (2007) Index of Wetland Condition. Methods Manual (draft)<br><ul style="list-style-type: none"> <li>• % of wetland perimeter with a buffer</li> <li>• Average buffer width</li> </ul> 3. Golus et al. (2006) Wetland Assessment Technique<br><ul style="list-style-type: none"> <li>• Width of fringing vegetation</li> </ul> 4. Davis et al. (2006) Wetlands bioassessment<br><ul style="list-style-type: none"> <li>• Percentage of undisturbed vegetation remaining within (100 m) of edge of wetland</li> </ul> |
| <b>Biota</b><br>represents the response of biota to changes in the environment. It may be based on sampling of biota sensitive and/or responsive to human disturbance across various scales |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |

## 9 Lacustrine and Palustrine Wetlands

| Indicator                                                                                                        | Measures and Methods                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Change in wetland vegetation                                                                                     | <p>REQUIRES MORE DEVELOPMENT AND EXPERT ADVICE –</p> <ul style="list-style-type: none"> <li>• Develop AusRivAS-style methods</li> <li>• Investigate Vegetation Matter for Target: <a href="http://www.nrm.gov.au/monitoring/indicators/vegetation-condition/index.html">http://www.nrm.gov.au/monitoring/indicators/vegetation-condition/index.html</a></li> <li>• Investigate Index of Wetland Condition methods (DSE 2007), Floodplain and Wetland Methods (MDBC 2005)</li> </ul> |
| Change in invertebrate diversity and community composition                                                       | <p>REQUIRES MORE DEVELOPMENT AND EXPERT ADVICE –</p> <ul style="list-style-type: none"> <li>• Develop AusRivAS-style methods</li> </ul>                                                                                                                                                                                                                                                                                                                                             |
| Change in wetland-dependent vertebrates (fish, frogs, reptiles, birds, mammals) presence, breeding and abundance | <p>Investigate current methods e.g.:</p> <ul style="list-style-type: none"> <li>• Fish: SRA, EHMP</li> <li>• Frogs: MDBC (frog calls)</li> <li>• Reptiles: no methods sourced</li> <li>• Birds: MDBC, Kingsford (in prep),</li> <li>• Mammals: no methods sourced</li> </ul>                                                                                                                                                                                                        |
| Change in introduced species (weeds and ferals) presence and abundance                                           | <p>There are several methods for introduced species presence and abundance listed in Appendix 8. Recommend investigation and trials to determine most suitable</p>                                                                                                                                                                                                                                                                                                                  |
| Change in algae (as a measure of primary productivity)                                                           | <p>REQUIRES MORE DEVELOPMENT AND EXPERT ADVICE</p>                                                                                                                                                                                                                                                                                                                                                                                                                                  |

## 9.2 AquaBAMM

AquaBAMM (Aquatic Biodiversity Assessment and Mapping Method) is a decision support method developed by Queensland EPA to assess conservation values in aquatic ecosystems through existing information and expert opinion. The non-riverine component of AquaBAMM is currently undergoing trials in Southeast Queensland. Whilst not strictly a method for determining resource condition, rather conservation values, criteria, indicators and measures are identified in the method. A comprehensive list of indicators and measures for non-riverine wetlands has been proposed, based on information and datasets readily available in Queensland (Table 43) (Clayton et al. 2006; P. Clayton pers.comm.). It is expected that this list will be finalised in mid-2008.

**Table 43. Proposed AquaBAMM criteria, indicators and measures for freshwater non-riverine wetlands.**

| Indicators                                 | Measures                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|--------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>1. Naturalness Aquatic (Diagnostic)</b> |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| Exotic flora/fauna                         | <ul style="list-style-type: none"> <li>• Presence of 'alien' fish species within the wetland</li> <li>• Presence of exotic aquatic and semi-aquatic plants within the wetland</li> <li>• Presence of exotic invertebrate fauna within the wetland</li> <li>• Presence of feral/exotic vertebrate fauna (other than fish) within the wetland (<i>expert panel list/discussion</i>)</li> </ul>                                                                                                          |
| Aquatic communities/assemblages            | <ul style="list-style-type: none"> <li>• Wetland condition – as measured by an acknowledged condition metric</li> </ul>                                                                                                                                                                                                                                                                                                                                                                               |
| Habitat features modification              | <ul style="list-style-type: none"> <li>• Snag removal within the wetland</li> <li>• % area of remnant wetland relative to preclear extent for each spatial unit</li> <li>• Presence of bund walls, ponded pastures, artificial waterbodies or other linear structures within the wetland</li> </ul>                                                                                                                                                                                                   |
| Hydrological modification                  | <ul style="list-style-type: none"> <li>• Mean annual extraction (or addition) (ML/year)</li> <li>• Hydrological disturbance/modification of the wetland (e.g. as determined through EPA wetland mapping and classification)</li> <li>• Presence of stormwater outlets within the wetland (<i>expert panel list/discussion</i>)</li> <li>• Influence of industrial outlets (STP &amp; aquaculture ) within the wetland with respect to water quantity (<i>expert panel list/discussion</i>)</li> </ul> |

# 9 Lacustrine and Palustrine Wetlands

| Indicators                                    | Measures                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|-----------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Water quality                                 | <ul style="list-style-type: none"> <li>• Median Total Phosphorous (ug/L)</li> <li>• Median Total Nitrogen (ug/L)</li> <li>• Median Turbidity (ug/L)</li> <li>• Median Conductivity (ug/L)</li> <li>• Median pH</li> <li>• Presence of harmful algal blooms (<i>expert panel list/discussion</i>)</li> <li>• Influence of industrial outlets (STP and aquaculture ) within the wetland with respect to water quality (<i>expert panel list/discussion</i>)</li> <li>• Water quality index/score – an acknowledged metric calculated considering local, state or national water quality guidelines.</li> </ul> |
| <b>2. Naturalness Catchment (Diagnostic)</b>  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| Exotic flora/fauna                            | <ul style="list-style-type: none"> <li>• Presence of exotic terrestrial plants in the assessment unit</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| Riparian disturbance                          | <ul style="list-style-type: none"> <li>• % area of remnant vegetation relative to preclear extent within buffered non-riverine wetland: 500 m buffer for wetlands <math>\geq 8</math> ha, 200 m buffer for smaller wetlands</li> </ul>                                                                                                                                                                                                                                                                                                                                                                       |
| Catchment disturbance                         | <ul style="list-style-type: none"> <li>• % 'agricultural' land-use area (i.e. cropping and horticulture)</li> <li>• % 'grazing' land-use area</li> <li>• % 'vegetation' land-use area (i.e. native veg + regrowth)</li> <li>• % 'settlement' land-use area (i.e. towns, cities, etc)</li> <li>• % area of known contaminated land adjacent to the wetland, measured within a 200 m buffer around the wetland</li> </ul>                                                                                                                                                                                      |
| Flow modification                             | <ul style="list-style-type: none"> <li>• Farm storage (overland flow harvesting, floodplain ring tanks, gully dams) calculated by surface area</li> <li>• % area of impervious surfaces within the assessment unit (typical of urban areas)</li> </ul>                                                                                                                                                                                                                                                                                                                                                       |
| <b>3. Diversity and Richness (Diagnostic)</b> |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| Species                                       | <ul style="list-style-type: none"> <li>• Richness of native fish</li> <li>• Richness of native aquatic dependent reptiles</li> <li>• Richness of native waterbirds</li> <li>• Richness of native aquatic plants (macrophytes)</li> <li>• Richness of native amphibians (non-riverine wetland breeders)</li> </ul>                                                                                                                                                                                                                                                                                            |
| Communities/assemblages                       | <ul style="list-style-type: none"> <li>• Number of macroinvertebrate taxa (Family level taxonomy)</li> <li>• Native fish biotic index (observed : expected ratio)</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| Habitat                                       | <ul style="list-style-type: none"> <li>• Richness of wetland types within the local catchment (e.g. SOR<sup>1</sup> sub-section</li> <li>• Richness of wetland types within the sub-catchment</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                     |

| Indicators                                                 | Measures                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Geomorphology                                              | <ul style="list-style-type: none"> <li>Richness of geomorphic features (i.e. features determined through a classification such as the GAR method)</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| <b>4. Threatened Species and Ecosystems (Diagnostic)</b>   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| Species                                                    | <ul style="list-style-type: none"> <li>Presence of rare or threatened aquatic ecosystem dependent fauna species – NCA<sup>6</sup>, EPBCAct<sup>7</sup></li> <li>Presence of rare or threatened aquatic ecosystem dependent flora species – NCA<sup>6</sup>, EPBCAct<sup>7</sup></li> </ul>                                                                                                                                                                                                                                                                                                                     |
| Communities/assemblages                                    | <ul style="list-style-type: none"> <li>Conservation status of wetland Regional Ecosystems – Herbarium biodiversity status, NCA<sup>6</sup>, EPBCAct<sup>7</sup></li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| <b>5. Priority Species and Ecosystems (Expert opinion)</b> |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| Species                                                    | <ul style="list-style-type: none"> <li>Presence of aquatic ecosystem dependent 'priority' fauna species (<i>expert panel list/discussion</i> or other lists such as ASFB<sup>9</sup>, WWF<sup>10</sup>, etc)</li> <li>Presence of aquatic ecosystem dependent 'priority' flora species (<i>expert panel list/discussion</i>)</li> <li>Habitat for, or presence of, migratory species (Expert Panel list/discussion and/or JAMBA<sup>11</sup> / CAMBA<sup>12</sup> agreement lists and Bonn Convention)</li> <li>Habitat for significant numbers of waterbirds (<i>expert panel list/discussion</i>)</li> </ul> |
| Ecosystems                                                 | <ul style="list-style-type: none"> <li>Presence of 'priority' aquatic ecosystem (<i>expert panel list/discussion</i>)</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| <b>6. Special Features (Expert opinion)</b>                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| Geomorphic features                                        | <ul style="list-style-type: none"> <li>Presence of distinct, unique or special geomorphic features (<i>expert panel list/discussion</i>)</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| Ecological processes                                       | <ul style="list-style-type: none"> <li>Presence of (or requirement for) distinct, unique or special ecological processes (<i>expert panel list/discussion</i>)</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| Habitat                                                    | <ul style="list-style-type: none"> <li>Presence of distinct, unique or special habitat (including habitat that functions as refugia or other critical purpose) (<i>expert panel list/discussion</i>)</li> <li>Significant wetlands identified by an accepted method such as Ramsar, Australian Directory of Important Wetlands, Regional Coastal Management Planning, World Heritage Areas, etc.</li> <li>Ecologically significant wetlands identified through expert opinion and/or documented study</li> </ul>                                                                                               |
| Hydrological                                               | <ul style="list-style-type: none"> <li>Presence of distinct, unique or special hydrological regimes (eg. Spring fed stream, ephemeral stream, boggomoss) (<i>expert panel list/discussion</i>)</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                      |
| <b>7. Connectivity (Expert opinion)</b>                    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| Significant species or populations                         | <ul style="list-style-type: none"> <li>The contribution (upstream or downstream) of the spatial unit to the maintenance of significant species or populations, including those features identified through Criteria 5 and/or 6 (<i>expert panel list/discussion</i>)</li> <li>Possibility for migratory or routine 'passage' of fish and other fully aquatic species (upstream, lateral or downstream movement) within the spatial unit</li> </ul>                                                                                                                                                             |

# 9 Lacustrine and Palustrine Wetlands

| Indicators                                | Measures                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|-------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Groundwater dependent ecosystems          | <ul style="list-style-type: none"> <li>The contribution (upstream or downstream) of the spatial unit to the maintenance of groundwater ecosystems with significant biodiversity values, including those features identified through Criteria 5 and/or 6 (e.g., karsts, cave streams, artesian springs) (<i>expert panel list/discussion</i>)</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Floodplain and wetland ecosystems         | <ul style="list-style-type: none"> <li>Extent to which the wetland retains critical ecological and hydrological connectivity, where it should exist, with floodplains, rivers, groundwater, etc. (<i>expert panel list/discussion</i>)</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| Terrestrial ecosystems                    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| Estuarine and marine ecosystems           | <ul style="list-style-type: none"> <li>The contribution of the spatial unit to the maintenance of estuarine and marine ecosystems with significant biodiversity values, including those features identified through Criteria 5 and/or 6 (<i>expert panel list/discussion</i>)</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| <b>8. Representativeness (Diagnostic)</b> |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| Wetland protection                        | <ul style="list-style-type: none"> <li>The percent area of each wetland type* within Protected Areas (National Park, State Forest, Conservation Park, Nature Refuge) under the Nature Conservation Act and/or relevant environment or conservation reserves under the Land Act.</li> <li>The percent area of each wetland type* within a coastal/estuarine area subject to the Fisheries Act, Coastal Management Act or Marine Parks Act.</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                        |
| Wetland uniqueness                        | <ul style="list-style-type: none"> <li>The relative abundance of the wetland management group to which the wetland belongs within the catchment or study area (management groups ranked least common to most common)</li> <li>The relative abundance of the wetland management group to which the wetland belongs within the sub-catchment (management groups ranked least common to most common)</li> <li>The size of each wetland relative to others of its management group within the catchment or study area</li> <li>The size of each wetland type* relative to others of its type within a sub-catchment</li> <li>Wetlands representative of the catchment – identified by expert opinion (<i>expert panel list/discussion</i>)</li> <li>The size of each wetland type* relative to others of its type within the catchment or study area</li> </ul> |

\* wetland type = habitat type; 1.State of the Rivers; 2.Stream Invertebrate Grade Number – Average Level; 3.Australian River Assessment System; 4.Ephemeroptera, Plecoptera, Trichoptera; 5.Annual Proportional Flow Deviation; 6.Nature Conservation Act; 7.Environment Protection and Biodiversity Conservation Act 1999; 8.Australian Society for Fish Biology; 9.World Wildlife Fund; 10.Japan–Australia Migratory Bird Agreement; 11.China–Australia Migratory Bird Agreement.

### 9.3 CRCFE Dryland Refugia

In many parts of the landscape, where ephemeral waterways are the norm, it is common to find riverine waterholes that behave more like lacustrine and palustrine wetlands. The CRCFE Dryland Refugia project (2001-2005) investigated several such waterholes in arid and semi-arid rivers of Queensland (Cooper Creek, Warrego River and the Border Rivers) to determine the relationships between biodiversity

and the physical attributes of individual waterholes, as well as the spatial and temporal pattern of connectivity in the landscape. An understanding of the importance of refugia in the landscape and how changes in hydrology and land management can influence the biological and physical processes was a major outcome. Many variables covering geomorphology, hydrology, and water quality were collected during the course of the project (Table 44) (Marshall et al 2006a). In addition, fish, macroinvertebrates, macrophytes, algae, and biophysical processes were sampled.

**Table 44. Physical variables measured in the Dryland Refugia project (Marshall et al. 2006a).**

| Variable class              | Variables                                                                                                                                                                                                                                               |                                                                                                                                                                                                                                                                 |
|-----------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Floodplain morphology       | <ul style="list-style-type: none"> <li>• Total flood plain width</li> <li>• Effective flood plain width</li> <li>• Flood plain setting</li> <li>• Bifurcation ratio</li> </ul>                                                                          | <ul style="list-style-type: none"> <li>• Number of channels</li> <li>• Channel distance to the nearest waterhole</li> <li>• Straight line distance to the nearest waterhole</li> </ul>                                                                          |
| Waterhole morphology        | <ul style="list-style-type: none"> <li>• Surface Area</li> <li>• Perimeter</li> <li>• Length</li> <li>• Width</li> <li>• Fetch length</li> <li>• Circularity</li> <li>• Elongation ratio</li> </ul>                                                     | <ul style="list-style-type: none"> <li>• Length to width ratio</li> <li>• Width to depth ratio</li> <li>• Hydraulic radius</li> <li>• Wetted perimeter</li> <li>• Shape index</li> <li>• Depth of cross-section</li> <li>• Volume</li> </ul>                    |
| Within waterhole morphology | <ul style="list-style-type: none"> <li>• Mid-channel bars</li> <li>• Backwater</li> <li>• Offtake channels</li> <li>• Bench 0 – 1/3</li> <li>• Bench 1/3 – 2/3</li> <li>• Bench 2/3 – 3/3</li> <li>• Side bars</li> <li>• Miscellaneous bars</li> </ul> | <ul style="list-style-type: none"> <li>• Anabranches</li> <li>• Bed and bank complexity</li> <li>• Eroding banks</li> <li>• Snag density</li> <li>• Scour holes</li> <li>• Boulders</li> <li>• Fringing vegetation</li> <li>• Overhanging vegetation</li> </ul> |

## 9 Lacustrine and Palustrine Wetlands

| Variable class | Variables                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|----------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Sample habitat | <ul style="list-style-type: none"> <li>• % deep (not sampleable)</li> <li>• % edge</li> <li>• % silt/clay pool</li> <li>• % sandy pool</li> <li>• % rocky pool</li> <li>• Edge algae density</li> <li>• Edge detritus density</li> <li>• Edge macrophyte density</li> <li>• Rocks</li> <li>• Mean wetted width</li> </ul>                                                                                                                                                  |
| Water quality* | <ul style="list-style-type: none"> <li>• Conductivity</li> <li>• Turbidity</li> <li>• Total nitrogen</li> <li>• Ratio total N: total P</li> <li>• DO 24 hr minimum</li> <li>• Water temperature 24 hr maximum</li> <li>• Silicate</li> <li>• Sulphate</li> </ul>                                                                                                                                                                                                           |
| Hydrology      | <ul style="list-style-type: none"> <li>• Time since discharge &gt;1500 ML/day</li> <li>• Time since discharge &gt;1000 ML/day</li> <li>• Time since discharge &gt;500 ML/day</li> <li>• Time since discharge &gt;50 ML/day</li> <li>• Total antecedent discharge in past 90 days</li> <li>• Total antecedent discharge in past 60 days</li> <li>• Total antecedent discharge in past 30 days</li> <li>• Duration of most recent high flow event &gt; 500 ML/day</li> </ul> |

\* only those WQ parameters used in the analyses are listed

## 9.4 Conceptual Models

One of the major outcomes of the Wetland Indicators Workshop was the development of conceptual models for Queensland lacustrine and palustrine wetlands (Maher et al. 2006). Several wetland subtypes common in Queensland were identified, and many of the key features, processes, pressures, drivers, impacts, responses and potential indicators listed. Time limited the number of wetland subtypes that could be modelled at the workshop, and it was also recognised after the event that most of the subtypes had been selected intuitively, rather than by an accepted process. This led to discussions with the Queensland Wetlands Joint Government Taskforce and a project extension to explore a formal wetland classification system for Queensland wetlands (Section 4). A new Queensland Wetlands Programme project will use the proposed Wetland Description Tool and this set of conceptual models to develop a complete set of conceptual models defined by a rigorous classification system pertinent to Queensland.

Four general conceptual models representing the wet and dry phases of generalised lacustrine and palustrine wetlands were built initially at the workshop. Following this stage, a set of wetland subtypes for each wetland type was proposed and the most common of those were modelled. All the models are presented in Tables 45 – 58 and Figures 7 – 22.

It is worth noting that these models have been cited several times only months after their development, in the literature (Norris et al. 2007), in training programs (DPI&F FMS,) and for presentations (R. Norris pers. comm.; A. McDougall pers. comm.; I. Layden pers. comm.). They have been used by the Australian Government in developing ecological character descriptions for Australia's Ramsar wetlands, and have been used by South Australia's DWLBC to assist in developing conceptual models for their wetlands as part of the National Wetland Indicators Review. Their usefulness in describing wetlands and ecological concepts has been proven.

### Lacustrine wetlands

**Table 45. Lacustrine wetlands conceptual model.**

| Lacustrine wetlands                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Key Features</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| <b>Physical</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| <ul style="list-style-type: none"> <li>• Surface area <math>\geq 8</math> ha</li> <li>• If <math>&lt; 8</math> ha, then must be deeper than 2 m (at deepest point when full)</li> <li>• Sediment substrate</li> <li>• Can have connectivity with other water bodies (leading to species dispersal)</li> <li>• Spatial complexity/ habitat complexity               <ul style="list-style-type: none"> <li>o Submerged debris as habitat</li> <li>o Bathymetry – shape of lake bed</li> <li>o Presence/absence of islands within the water body</li> </ul> </li> </ul> |

continued on next page

# 9 Lacustrine and Palustrine Wetlands

Table 45 continued from previous page

| Lacustrine wetlands                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p><b>Hydrology</b></p> <ul style="list-style-type: none"> <li>• Water dominated</li> <li>• Water source: groundwater/overland flow/precipitation/channel overflow</li> <li>• Water inflow regime: pulsing of water, or single large influx event</li> <li>• Evaporation</li> <li>• Mixing by wind</li> <li>• Velocity/water movement/flow rates/flushing</li> <li>• Stratification</li> <li>• Wetting/drying – fluctuation may occur</li> </ul> <p><b>Physico-chemical</b></p> <ul style="list-style-type: none"> <li>• Water regime and chemistry</li> <li>• Nutrients input: overland flow/allochthonous/groundwater</li> <li>• Sediment and nutrient input</li> <li>• Water quality <ul style="list-style-type: none"> <li>o Ionic composition</li> <li>o Organic matter</li> <li>o pH</li> </ul> </li> <li>• Light climate variable – clear/turbid/tannin stained/stratification</li> <li>• Interaction between plants and light climate</li> </ul> <p><b>Biota</b></p> <ul style="list-style-type: none"> <li>• Without emergent vegetation over most of the wetland extent</li> <li>• Submerged vegetation/ macrophyte vegetation (depth limited – generally &lt;3 m, but can be much deeper if turbidity is very low)</li> <li>• Riparian buffer zones</li> <li>• Allochthonous input (organic material produced by photosynthesis outside the wetland e.g. leaf litter)</li> <li>• Autochthonous input (organic material produced by photosynthesis within the wetland e.g. aquatic plants)</li> <li>• Primary production – light/temperature controlled</li> <li>• Macrofauna – in and on water (birds, fish, turtles, frogs etc)</li> <li>• Nesting birds – affecting nutrients</li> <li>• Macroinvertebrates (grazers at edges)</li> <li>• Extent (depth and duration of water affecting vegetation)</li> <li>• Dynamic exchange between benthic, littoral, and pelagic zones</li> </ul> |

### Lacustrine wetlands

- Algae
  - o Phytoplankton
  - o Algal 'bath tub rings' at the water line, particularly in arid zones
  - o Attached or benthic algae
- Zooplankton
- Bacterioplankton
  - o Autotrophic
  - o Heterotrophic
- Benthic microbiota

### Processes

- Sedimentation
- Biogeochemical cycling of nitrogen, phosphorus and carbon
- Temporal fluctuations (including seasonal/cyclical)
- Bush fire: successional phenomena – life cycle phases – hydrological variation giving successional ecology and morphology
- Set of meta-stable states or continuous variation

### Drivers

- Hydrology
  - o Water depth
  - o Groundwater exchange
  - o Source
  - o Evaporation
  - o Surface run-off
  - o Connectivity
  - o Seasonality
  - o Duration and frequency
  - o Flushing regime
- Light
  - o Turbidity
  - o Stratification
  - o Tannins/colour

continued on next page

# 9 Lacustrine and Palustrine Wetlands

Table 45 continued from previous page

| Lacustrine wetlands                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <ul style="list-style-type: none"> <li>• Water quality               <ul style="list-style-type: none"> <li>o pH</li> <li>o Conductivity and ionic composition</li> <li>o Nutrients and organic matter</li> <li>o Hardness</li> <li>o Dissolved oxygen</li> </ul> </li> <li>• Habitat complexity               <ul style="list-style-type: none"> <li>o Within lake microhabitats</li> <li>o Lake geomorphology and shape</li> <li>o Landscape/catchment position</li> <li>o Sediment/substrate composition</li> </ul> </li> </ul>                                                                                                                        |
| Pressures                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| <ul style="list-style-type: none"> <li>• Biota (cover and type)</li> <li>• Water regime</li> <li>• Timing</li> <li>• Flow duration, size, frequency</li> <li>• Acidic conditions</li> <li>• Waterbody margins</li> <li>• Nutrients</li> <li>• Deposition</li> <li>• Weeds</li> <li>• Exotic animals</li> <li>• Human impacts</li> <li>• Lake bed cropping/grazing when dry</li> </ul>                                                                                                                                                                                                                                                                     |
| Potential Indicators                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| <ul style="list-style-type: none"> <li>• Photic depth</li> <li>• Nutrient status</li> <li>• Salinity</li> <li>• Aerial extent (remote sense based) fluctuations, aerial extent of wetted area</li> <li>• Turbidity (couple remote sensing and on-ground data at selected sites)</li> <li>• Fringing vegetation fluctuations in response to impacts e.g. river red gum deaths</li> <li>• Changes in amount of surface area that falls into certain categories – defined by ratio between euphotic depth and total depth.</li> <li>• Oxygen profile – the point at which oxygen falls below thresholds for diverse macroinvertebrate populations</li> </ul> |

### Lacustrine wetlands

- Those that do/don't have enough oxygen all day, and those that have enough for part of the day
- Weediness (proportion of weeds in aquatic vegetation)
- Biota – diversity and abundance
- Spatial extent, specifically in terms of existence value.
- Spatial extent and events which may change the surface area:
  - o Water quantity
  - o Hydrological fluctuations
  - o Water quality
  - o Range of ecological functions
- Trophic status
- Chlorophyll a
- Algal blooms
- Extent – 'reference extent model' for types of lacustrine
- Hydrological regime – disturbed/modified/deviation from natural
- Deviation from expected hydrology
- Deviation from expected riparian vegetation
- Landscape function analysis: catchment contribution, erosion, irrigation
- Use of the wetland (for recruitment, roosting, moulting, migration stopover)

# 9 Lacustrine and Palustrine Wetlands

Figure 7. Lacustrine wetland (wet phase) conceptual model.

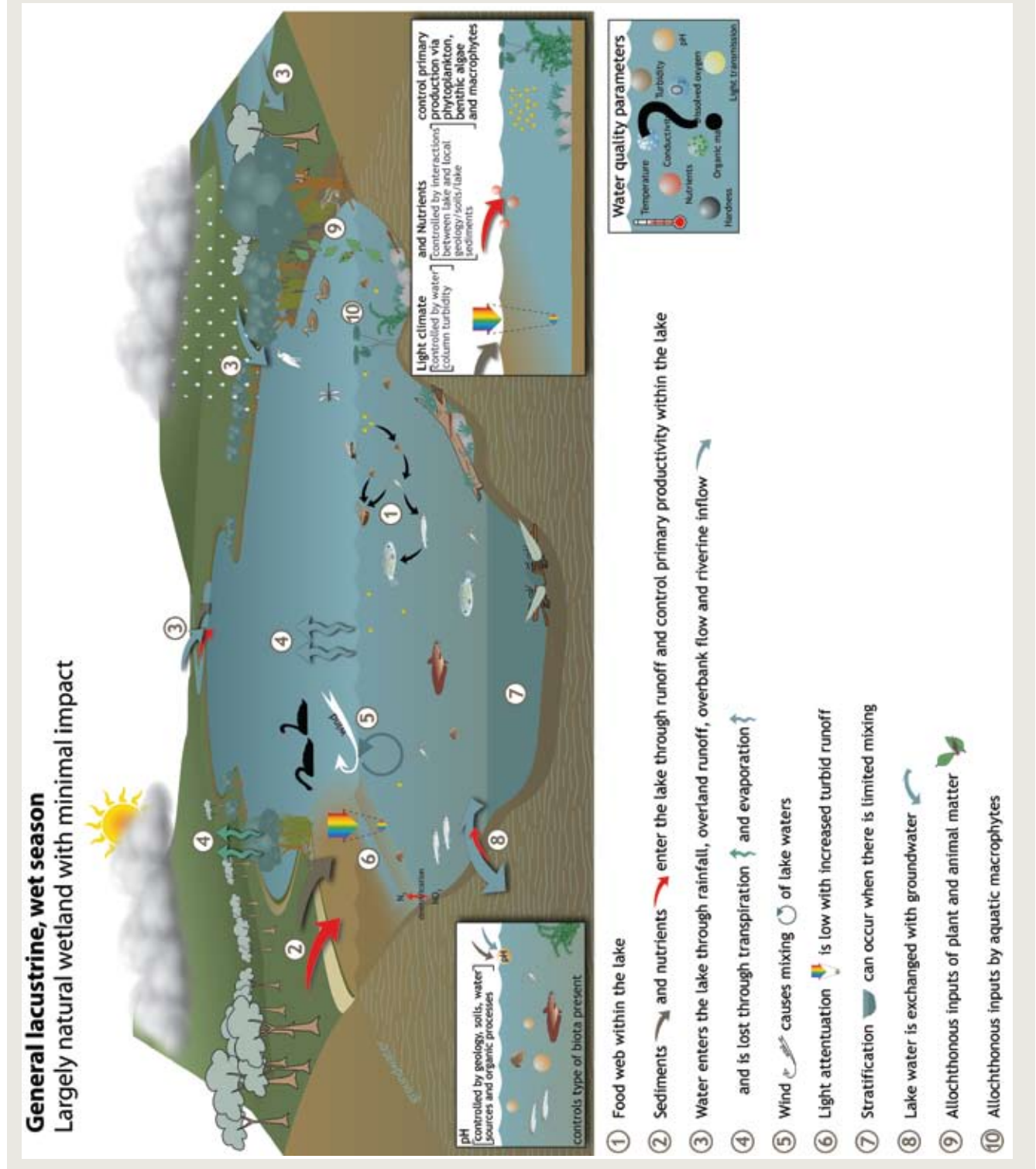
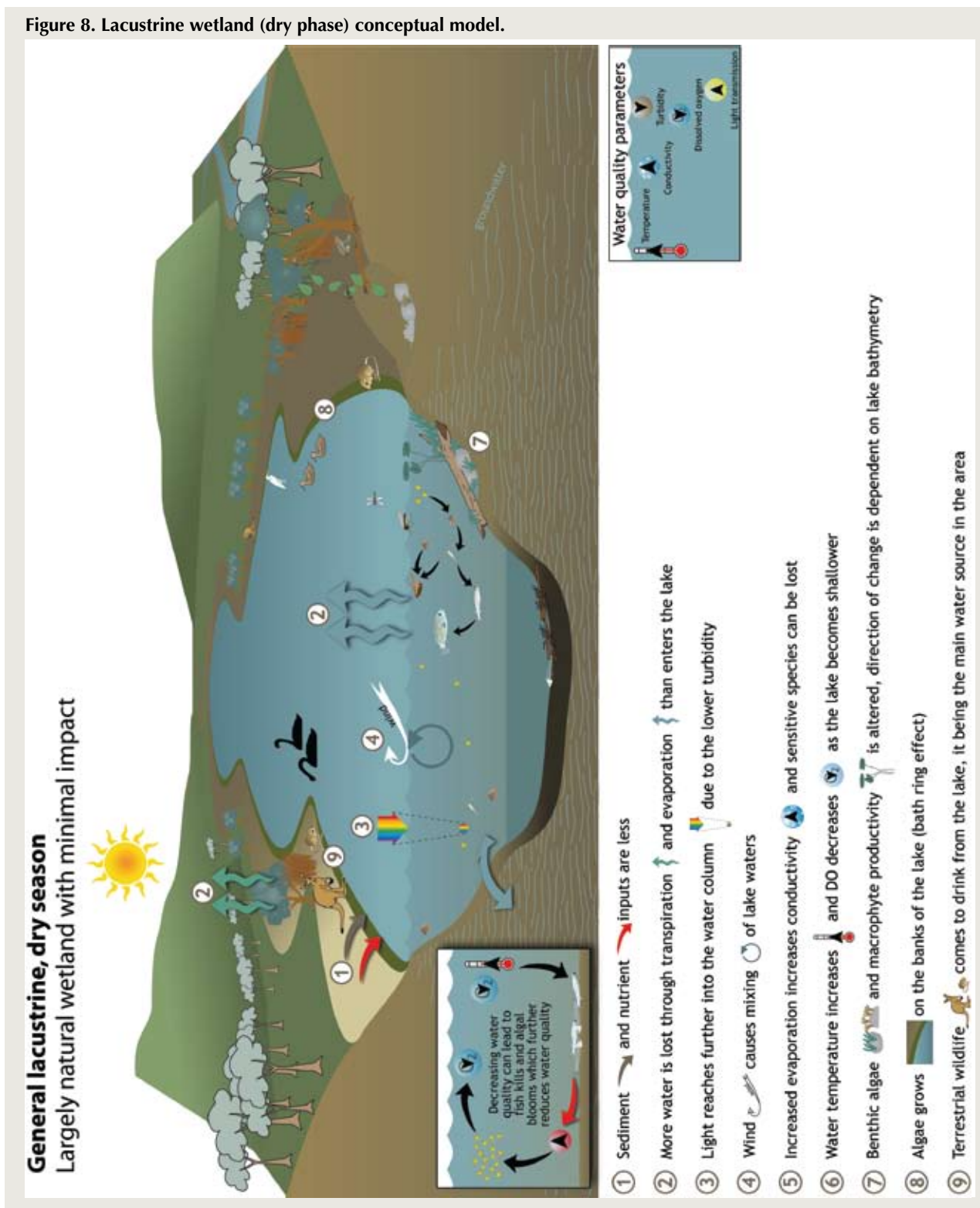


Figure 8. Lacustrine wetland (dry phase) conceptual model.

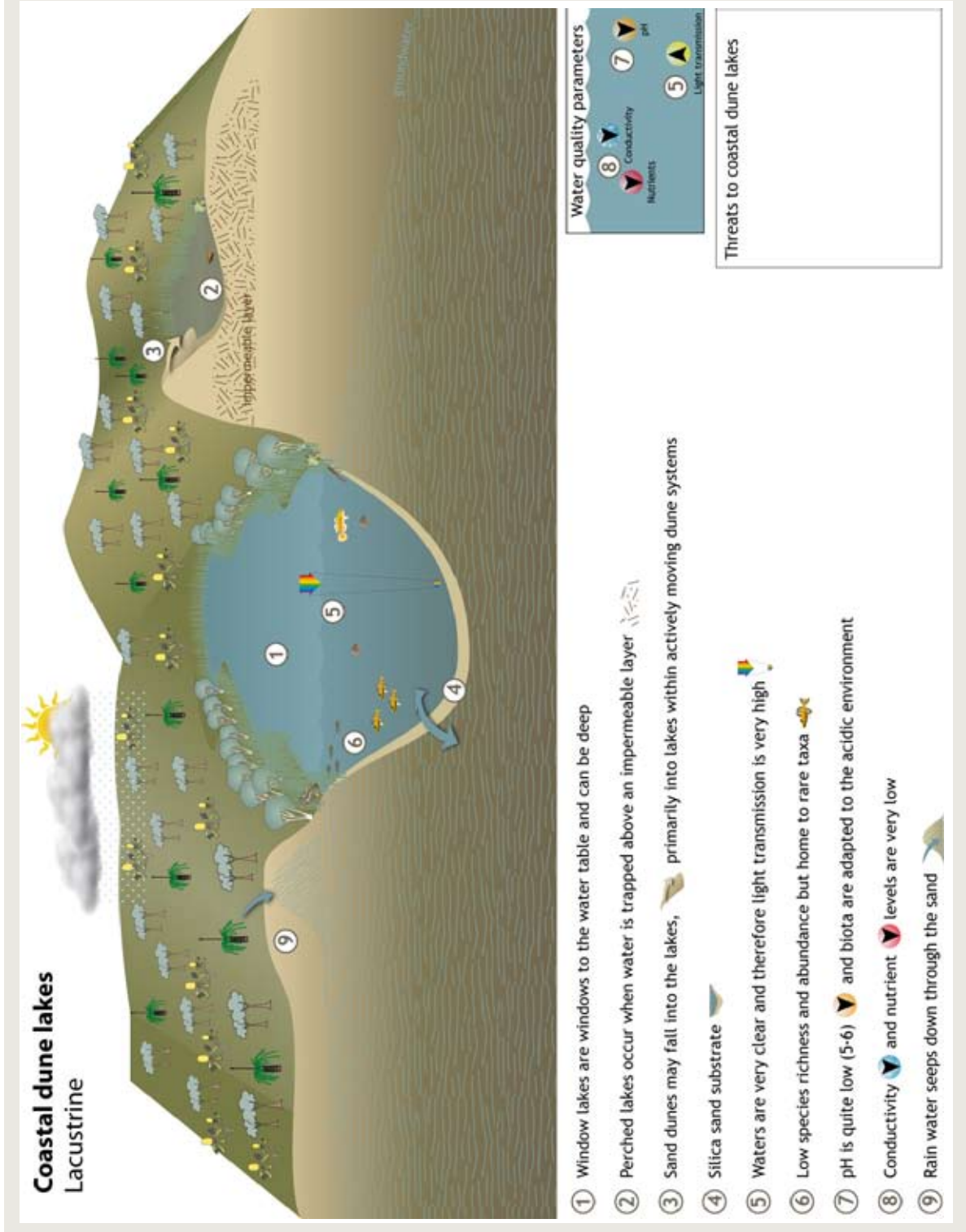


# 9 Lacustrine and Palustrine Wetlands

**Table 46. Conceptual model for coastal dune lakes.**

| Coastal dune lakes eg. Blue Lake, Stradbroke Island (window lake)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |  |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--|
| <b>Key Features</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |  |
| <ul style="list-style-type: none"> <li>Physical                             <ul style="list-style-type: none"> <li>High stability, low variability</li> <li>Regional watertable fluctuates slowly</li> <li>High transparency (light may reach bottom)</li> <li>Silica sand substrate</li> <li>Deep</li> <li>Majority of three dimensional habitat is emergent macrophytes</li> </ul> </li> <li>Hydrological                             <ul style="list-style-type: none"> <li>Groundwater exchange</li> <li>Precipitation runoff and percolation through sand</li> </ul> </li> <li>Physico-chemical                             <ul style="list-style-type: none"> <li>pH slightly acid 5-6</li> <li>Conductivity very low (&lt;100 µS/cm (Na, Cl))</li> <li>pH of groundwater 7.5 (key to ecology)</li> <li>Low nutrients</li> <li>Low productivity</li> </ul> </li> <li>Biota                             <ul style="list-style-type: none"> <li>Adapted to slightly acidic water</li> <li>Low species richness and abundance (low biomass, rare species)</li> </ul> </li> </ul> |  |
| <b>Pressures</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |  |
| <ul style="list-style-type: none"> <li>Water regime change</li> <li>Acidic condition change</li> <li>Nutrient status change</li> <li>Vegetation clearing and dune movement</li> <li>Tourism</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |  |
| <b>Ecological responses</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |  |
| <ul style="list-style-type: none"> <li>pH and conductivity change could equate to a change in community structure, and loss of the current ecological system</li> <li>Change in water level can lead to change in three-dimensional habitat (reeds), which supports biota</li> <li>Loss of unique organisms and influx of ubiquitous organisms</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |  |
| <b>Knowledge gaps</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |  |
| <ul style="list-style-type: none"> <li>Acidity (not pH) – an understanding of the conditions that lead to acidity.</li> <li>Infiltration effects</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |  |
| <b>Measurement</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |  |
| <ul style="list-style-type: none"> <li>There is a possibility of remote sensing to show the extent of the water body.</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |  |

Figure 9. Coastal dune lake (lacustrine) conceptual model.

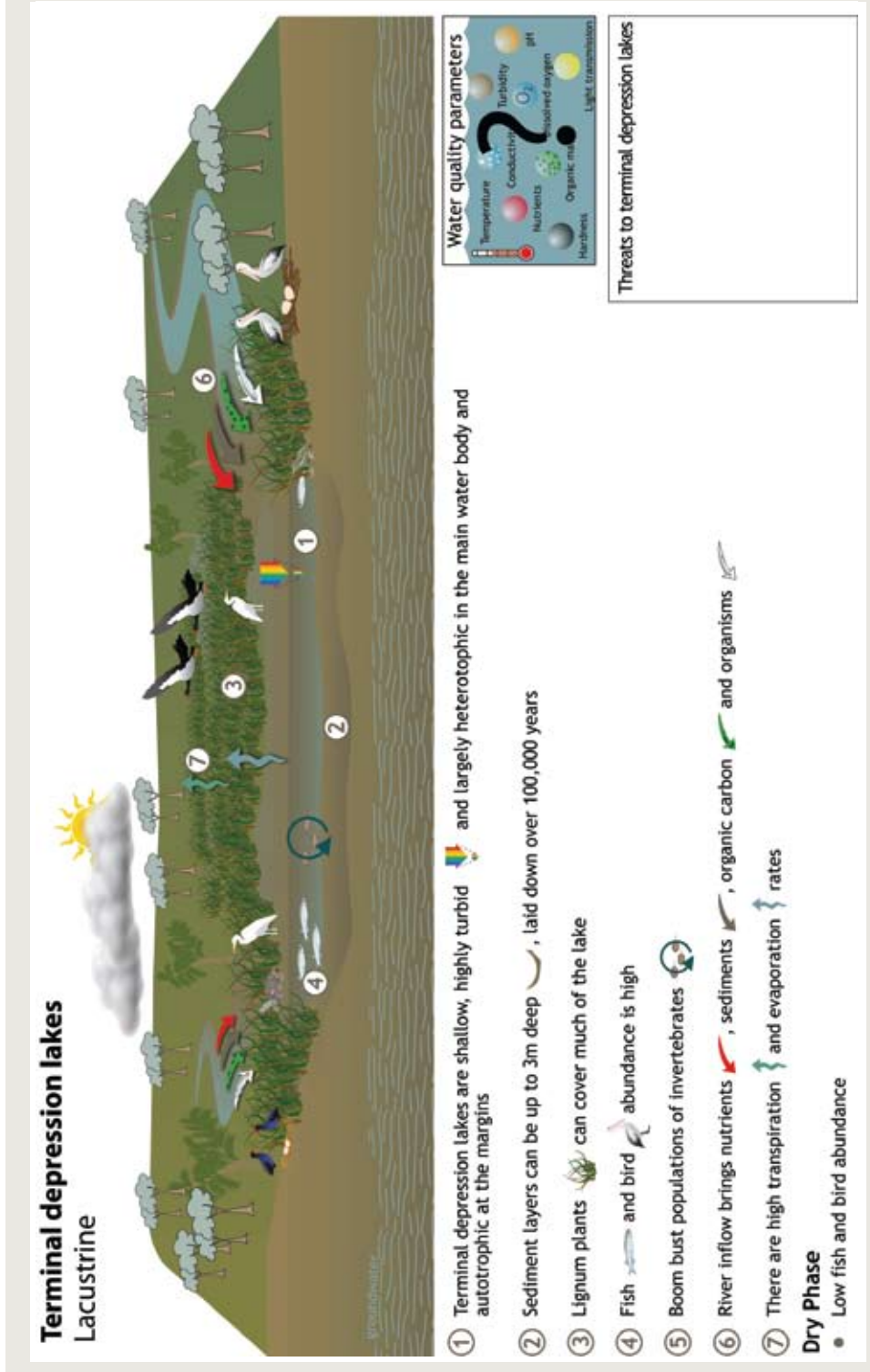


# 9 Lacustrine and Palustrine Wetlands

**Table 47. Conceptual model for terminal depression lakes.**

| Terminal depression lakes                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p><b>Key Features</b></p> <p><b>Wet phase</b></p> <ul style="list-style-type: none"> <li>• Physical <ul style="list-style-type: none"> <li>◦ Shallow 0-2 m, large extent (&gt;8 Ha)</li> <li>◦ Unlikely to stratify (low mixing)</li> <li>◦ 2.5 m sediment, up to 100,000 years deposition</li> <li>◦ Channel network, overflow outlet</li> </ul> </li> <li>• Hydrological <ul style="list-style-type: none"> <li>◦ Main input is river inflow containing nutrients, carbon, sediment and organisms</li> </ul> </li> <li>• Physico-chemical <ul style="list-style-type: none"> <li>◦ Highly turbid (light penetration 0-2 cm)</li> </ul> </li> <li>• Biota <ul style="list-style-type: none"> <li>◦ Autotrophic at margins (primary producers: algae, plants)</li> <li>◦ Heterotrophic in main water body (consumers)</li> <li>◦ Large populations of birds and fish</li> </ul> </li> </ul> <p><b>Dry phase</b></p> <ul style="list-style-type: none"> <li>• Physical <ul style="list-style-type: none"> <li>◦ Large areas of bare cracking clays</li> <li>◦ Soil turnover (important)</li> </ul> </li> <li>• Hydrological <ul style="list-style-type: none"> <li>◦ Can dry completely</li> </ul> </li> <li>• Biota <ul style="list-style-type: none"> <li>◦ Aquatic organisms take refuge in the sediments</li> <li>◦ Increase in terrestrial fauna</li> <li>◦ Lignum becomes habitat for terrestrial animals, including ferals</li> </ul> </li> </ul> |
| <p><b>Pressures</b></p> <ul style="list-style-type: none"> <li>• Hydrological</li> <li>• Quantity and duration of water retention has the most significant effect</li> <li>• Flow regime change</li> <li>• Reduced extent</li> <li>• Reduced waterbird, fish populations</li> <li>• Reduction in amplitude and frequency of flows</li> <li>• Sedimentation change</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| <p><b>Indicators</b></p> <ul style="list-style-type: none"> <li>• Hydrological regime: temporal and spatial</li> <li>• Model the relationship between inflows and extent of water body</li> <li>• Vegetation extent and structure, lignum regeneration</li> <li>• Breeding success of colonial waterbirds</li> <li>• Fish population species and abundance</li> <li>• Water temperature and quality</li> <li>• Total grazing pressure</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |

Figure 10. Terminal depression lakes (lacustrine) conceptual model.



# 9 Lacustrine and Palustrine Wetlands

**Table 48. Conceptual model for depression lakes (inland, non-arid).**

| Depression lakes (inland, non-arid)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p><b>Key Features</b></p> <ul style="list-style-type: none"> <li>• Depression in the floodplain</li> </ul> <p><b>Wet phase</b></p> <ul style="list-style-type: none"> <li>• Physical <ul style="list-style-type: none"> <li>o 8-9 m deep</li> <li>o Depositional environment (fine sediment substrate)</li> <li>o Can have levees</li> <li>o At low water levels, the process of wind re-suspension of bottom sediments is significant</li> <li>o Habitats reset by large overbank flow events</li> </ul> </li> <li>• Hydrological <ul style="list-style-type: none"> <li>o Stratification can occur</li> <li>o Sources: local storm events (direct precipitation and overland flows), overbank flows from local channels (less frequent but can be largest)</li> <li>o Groundwater interaction</li> <li>o Seasonal draw down</li> <li>o Influenced by local geography (height of surrounding landscape) and access to overbank flows</li> </ul> </li> <li>• Physico-chemical <ul style="list-style-type: none"> <li>o Variable turbidity</li> <li>o Turbidity influenced by nature and frequency of overbank flows</li> </ul> </li> <li>• Biota <ul style="list-style-type: none"> <li>o Very productive – biota, fish, birds, turtle etc</li> <li>o High diversity</li> <li>o Fringe riparian vegetation</li> <li>o Macrophyte beds and emergent vegetation in the littoral zone</li> </ul> </li> </ul> |

### Depression lakes (inland, non-arid)

#### Dry phase

- Physical
  - o Settling of sediment in bottom of depression, resulting in changes in the bathymetry
- Hydrological
  - o No open water
- Physico-chemical
  - o Dissolved oxygen <8% saturation
  - o Organic substrate becomes anoxic
- Biota
  - o Floating aquatic weed infestations
  - o Change in faunal composition to more tolerant taxa

#### Drivers

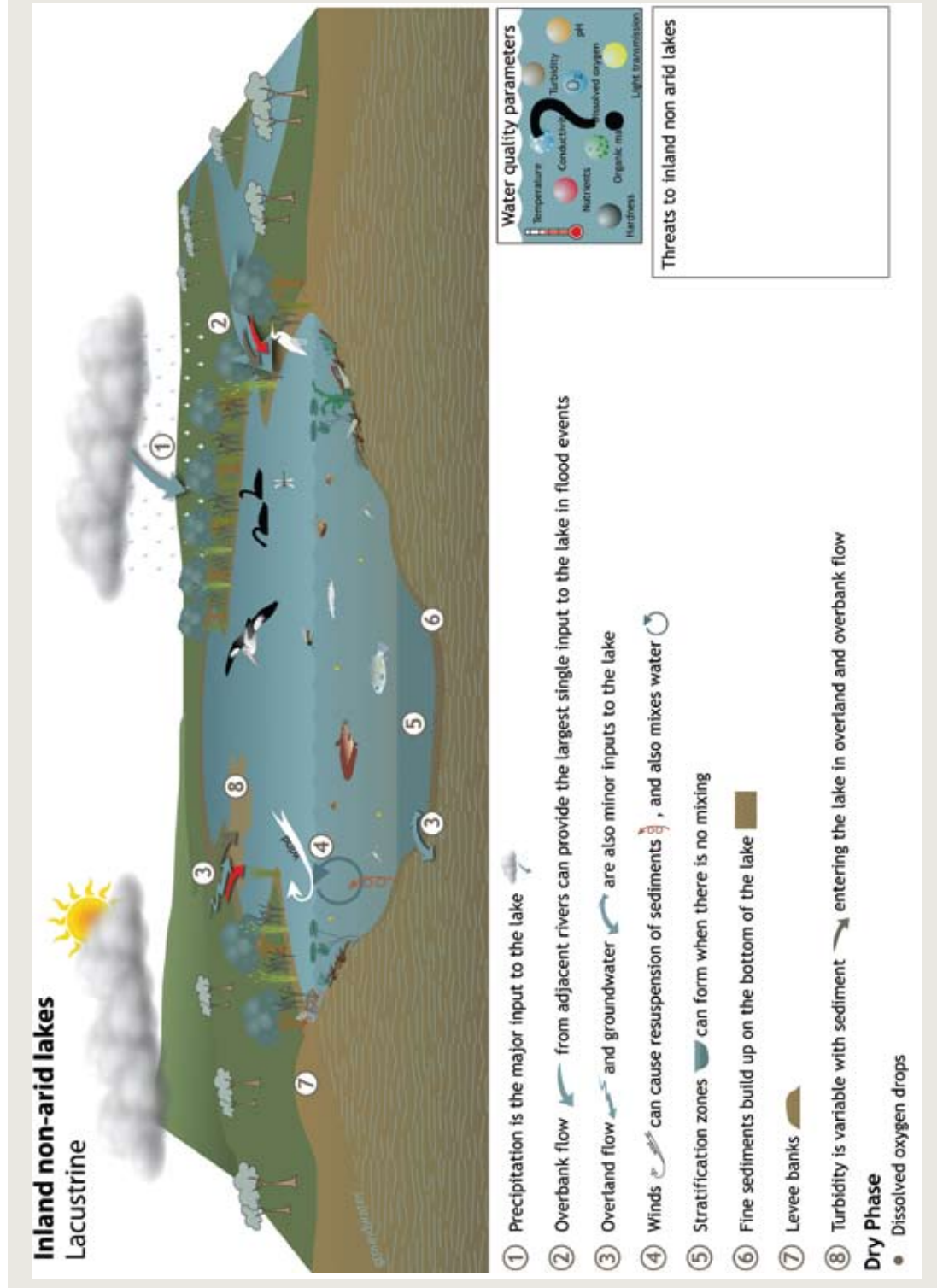
- Sediment and nutrient loads and nature of delivery
- Hydrological regime including groundwater (inflow/outflow/volume)
- Water quality
- Timing of inputs
- Connectivity with other waterbodies
- Aquatic plant community (including phytoplankton and algae)

#### Indicators

- Open water coverage
- Changes in aquatic fauna and flora composition and abundance
- Light
- Dissolved oxygen

# 9 Lacustrine and Palustrine Wetlands

Figure 11. Inland non-arid lakes (lacustrine) conceptual model.

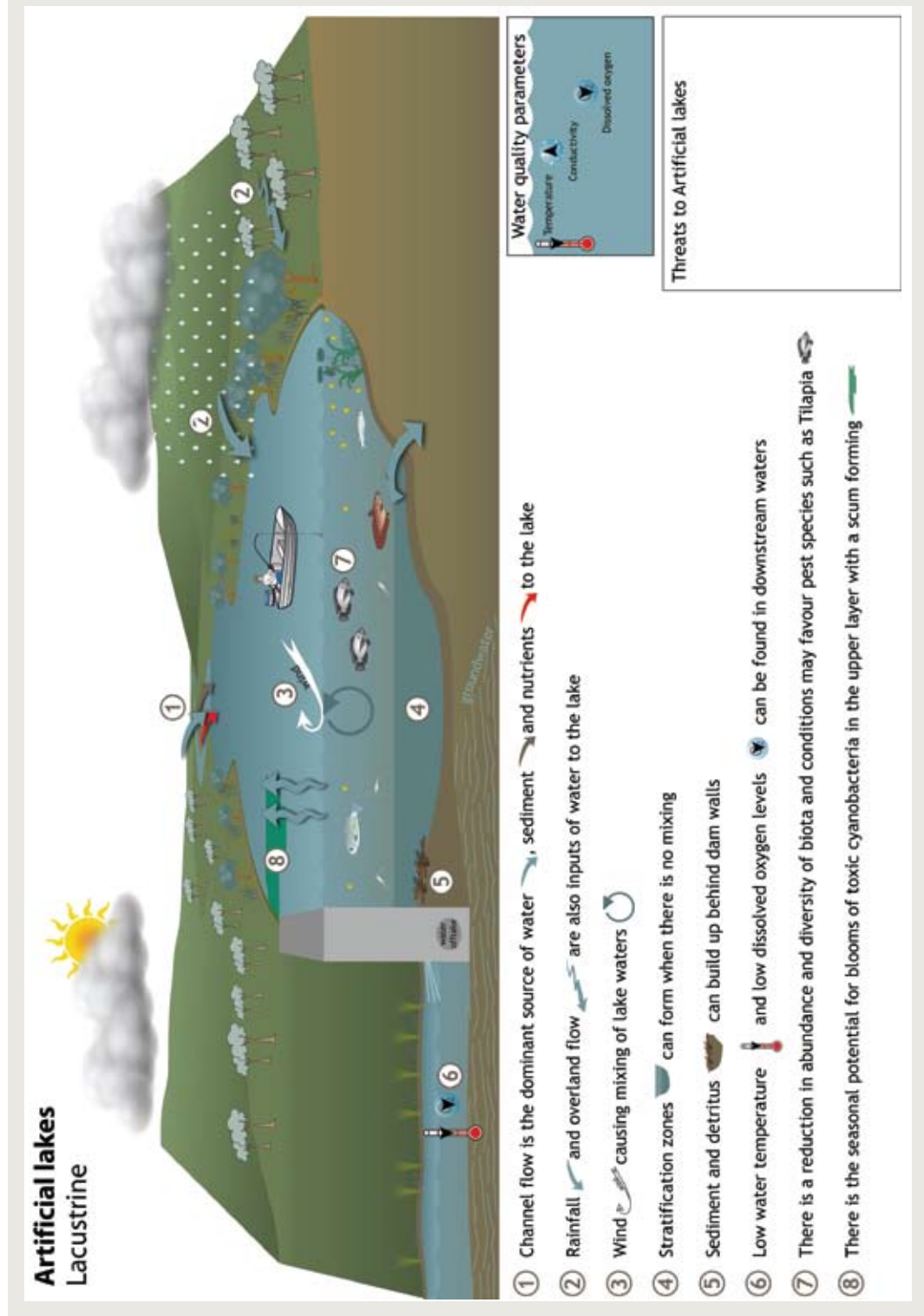


**Table 49. Conceptual model for artificial lakes.**

| Artificial lakes e.g. Water supply dam                                                                                                                                                                                                                                                                                                                                                                                       |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| The environmental and ecological values of this lacustrine sub-type are a low priority, so position within the catchment/landscape was not assessed.                                                                                                                                                                                                                                                                         |
| <p><b>Key Features</b></p> <p><b>Full dam</b></p> <ul style="list-style-type: none"> <li>• Large impounded surface area</li> <li>• Mixing (by wind)</li> </ul> <p><b>Low dam</b></p> <ul style="list-style-type: none"> <li>• Settling of sediments behind dam wall</li> <li>• Reduction in biota composition and abundance</li> <li>• Increased grazing pressures around dam margins leading to nutrient loading</li> </ul> |
| <p><b>Pressures</b></p> <ul style="list-style-type: none"> <li>• Hydrological regime (raising and lowering of dam level)</li> </ul>                                                                                                                                                                                                                                                                                          |
| <p><b>Drivers</b></p> <ul style="list-style-type: none"> <li>• Function e.g. water supply (as opposed to environmental value)</li> <li>• Level of function (potable vs. irrigation)</li> <li>• Ability to support threatened species</li> <li>• Hydrological regime (volume and timing of filling and release)</li> </ul>                                                                                                    |
| <p><b>Responses</b></p> <ul style="list-style-type: none"> <li>• Water quality degradation</li> <li>• Increase in algae and nutrients</li> <li>• Increase in turbidity</li> <li>• Decrease in biota</li> </ul>                                                                                                                                                                                                               |
| <p><b>Indicators</b></p> <ul style="list-style-type: none"> <li>• Water quality</li> <li>• Biota composition</li> <li>• Indicators specific to threatened species</li> <li>• Spatial extent of wetted area (remote sensing)</li> </ul>                                                                                                                                                                                       |

## 9 Lacustrine and Palustrine Wetlands

Figure 12. Artificial lakes (lacustrine) conceptual model.

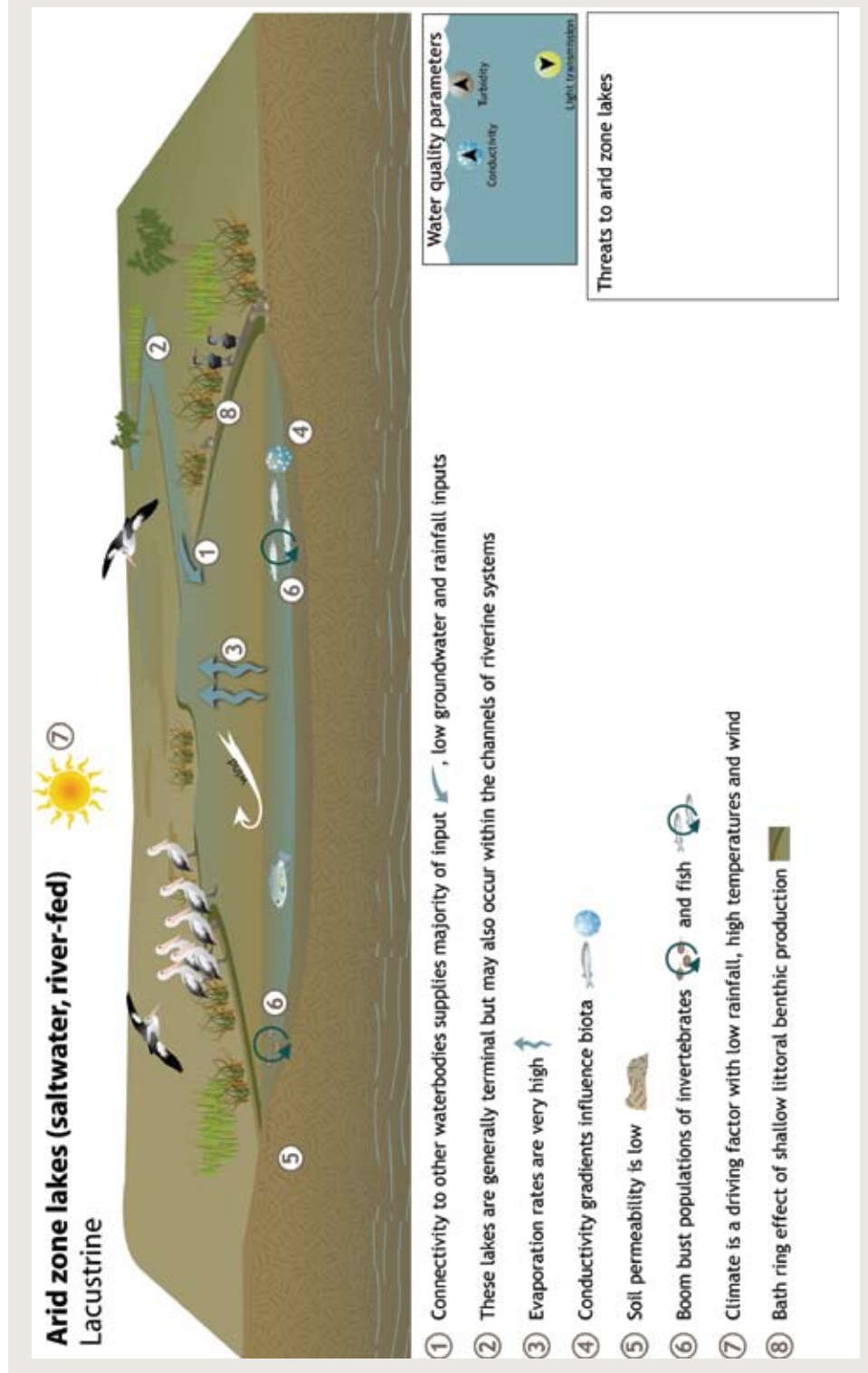


**Table 50. Conceptual model for arid-zone saltwater river-fed lakes.**

| Arid-zone saltwater river-fed lakes |                                                                                                                                                                                                                                                                                                                                                                                                                              |
|-------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Key Features</b>                 | <ul style="list-style-type: none"> <li>• Large terminal wetlands</li> <li>• Three phases: drought/flooding/drying</li> <li>• High evaporation rates</li> <li>• Low groundwater and rainfall inputs</li> <li>• Connectivity to other waterbodies supplies majority of input</li> <li>• Low soil permeability</li> <li>• Basin shape provides the habitat complexity</li> <li>• Salinity gradients govern the biota</li> </ul> |
| <b>Drivers</b>                      | <ul style="list-style-type: none"> <li>• Climate               <ul style="list-style-type: none"> <li>◦ Rainfall</li> <li>◦ Temperature</li> <li>◦ Wind</li> <li>◦ Lack of high riparian vegetation</li> </ul> </li> <li>• Hydrology (externally driven)</li> <li>• Connectivity</li> <li>• Soil type</li> <li>• Basin shape</li> <li>• Water chemistry</li> </ul>                                                           |
| <b>Pressures</b>                    | <ul style="list-style-type: none"> <li>• Flood harvesting (external to site)</li> </ul>                                                                                                                                                                                                                                                                                                                                      |
| <b>Responses</b>                    | <ul style="list-style-type: none"> <li>• Extent and duration of inundation</li> <li>• Vegetative zone shift</li> <li>• Salinity (more saline)</li> <li>• Reduction in fish and bird populations</li> </ul>                                                                                                                                                                                                                   |
| <b>Indicators</b>                   | <ul style="list-style-type: none"> <li>• Biota at a 'whole of system' scale (fish, waterbirds, plants)</li> <li>• Long-term monitoring (due to short term noise)</li> </ul>                                                                                                                                                                                                                                                  |

## 9 Lacustrine and Palustrine Wetlands

Figure 13. Arid zone lakes (lacustrine) conceptual model.



**Table 51. Conceptual model for inland salt lakes.**

| Inland salt lakes                                         |  |
|-----------------------------------------------------------|--|
| <b>Key Features</b>                                       |  |
| • Physical                                                |  |
| o Salt crust in dry phase                                 |  |
| o Sand and clay substrate                                 |  |
| o High temperature                                        |  |
| • Hydrological                                            |  |
| o Low rainfall                                            |  |
| o Highly variable hydrological regime                     |  |
| o Source: overland flow (groundwater interaction unknown) |  |
| o Filling and drying cycles                               |  |
| • Physico-chemical                                        |  |
| o Turbidity/salinity cycle                                |  |
| • Biota                                                   |  |
| o Boom and bust cycles                                    |  |
| o Limited riparian vegetation (e.g. saltbush)             |  |
| <b>Drivers</b>                                            |  |
| • Water quality                                           |  |
| o Salinity/turbidity cycle                                |  |
| o Colour                                                  |  |
| o pH                                                      |  |
| o Temperature                                             |  |
| o Nutrients                                               |  |
| o Dissolved oxygen                                        |  |
| o Light                                                   |  |
| • Hydrology (externally driven)                           |  |
| • Connectivity                                            |  |
| • Soil type                                               |  |
| • Basin shape                                             |  |
| • Water chemistry                                         |  |

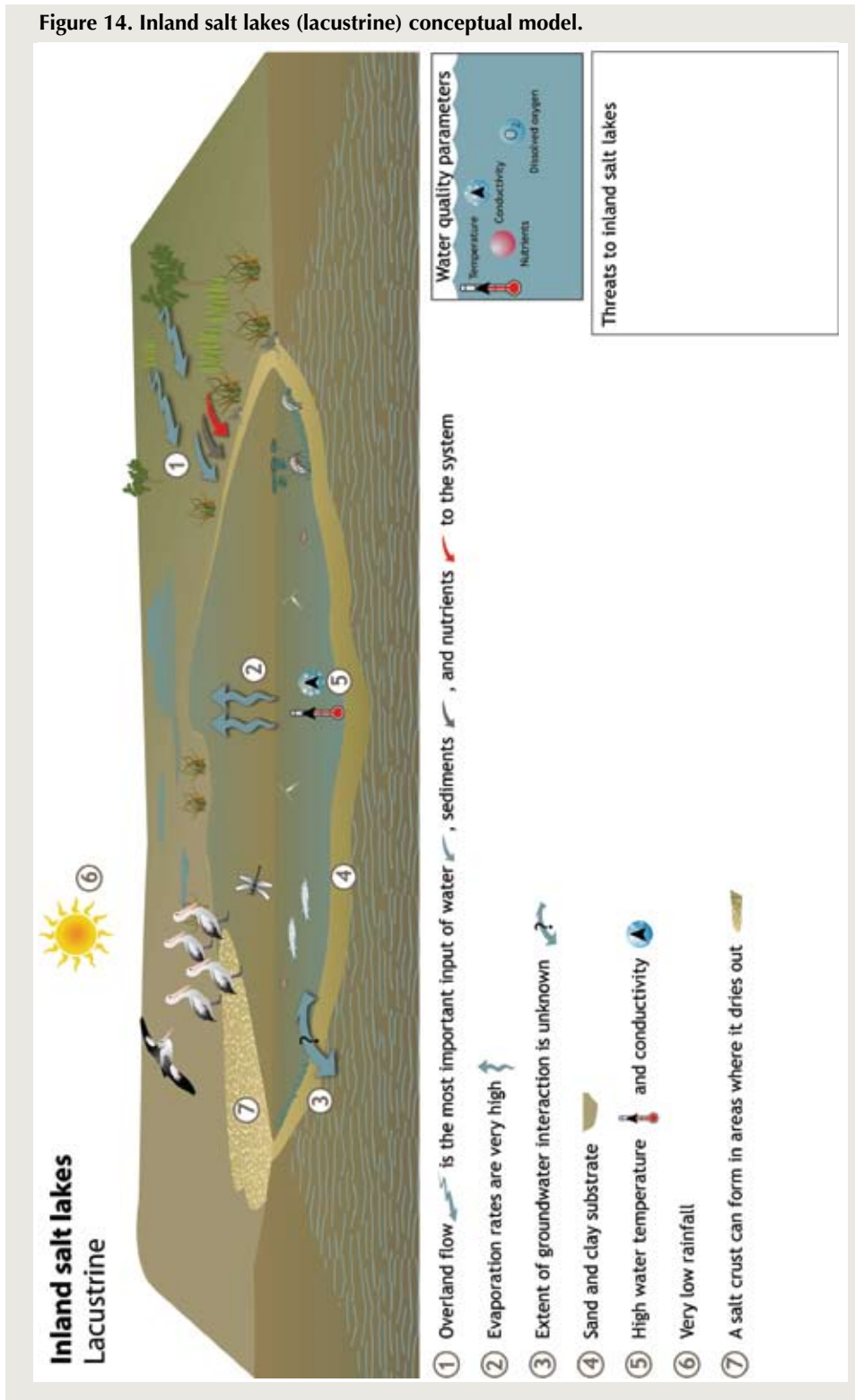
continued on next page

# 9 Lacustrine and Palustrine Wetlands

Table 51 continued from previous page

| Inland salt lakes                                                                                                                                                                                                                                                                                                                   |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Pressures</b> <ul style="list-style-type: none"><li>• Reduction in filling events (climate change)</li><li>• Increased grazing</li><li>• Extractive industries (unknown)</li></ul>                                                                                                                                               |
| <b>Indicators</b> <ul style="list-style-type: none"><li>• Rainfall</li><li>• Evaporation</li><li>• Hydrological regime</li><li>• Biota (invertebrates, fish, waterbirds)</li><li>• Water quality<ul style="list-style-type: none"><li>o Salinity/turbidity cycle</li><li>o Nutrients</li><li>o Dissolved oxygen</li></ul></li></ul> |

Figure 14. Inland salt lakes (lacustrine) conceptual model.



# 9 Lacustrine and Palustrine Wetlands

## Palustrine Wetlands

**Table 52. Palustrine wetlands conceptual model.**

| Palustrine wetlands                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p><b>Key Features</b></p> <p><b>Physical</b></p> <ul style="list-style-type: none"> <li>• Area is not defined</li> <li>• Generally shallow (Max depth 2 m)</li> <li>• If water is ponded, it may only be a small amount which often dries up</li> <li>• Gradual edge/bank</li> </ul> <p><b>Hydrology</b></p> <ul style="list-style-type: none"> <li>• Typically have dominant drying phase</li> <li>• Sources: groundwater, local, floodplain, riverine</li> <li>• Groundwater/surface exchange</li> </ul> <p><b>Physico-chemical</b></p> <ul style="list-style-type: none"> <li>• Variable water quality</li> <li>• Organic loading</li> <li>• Soil condition is important (peat, acid sulfate soils)</li> </ul> <p><b>Biota</b></p> <ul style="list-style-type: none"> <li>• Vegetation dominated (palms, trees, shrubs, grass/sedges, aquatic vegetation)</li> <li>• Shrubs (e.g. lignum) in water</li> <li>• Vegetation usually perennial</li> <li>• Can be submerged macrophyte beds (but not the only type of vegetation)</li> <li>• Boom and bust cycles in ephemeral wetlands</li> <li>• Fauna</li> </ul> |
| <p><b>Processes</b></p> <ul style="list-style-type: none"> <li>• Allochthonous input (organic material produced by photosynthesis outside the wetland e.g. leaf litter)</li> <li>• Autochthonous input (organic material produced by photosynthesis within the wetland e.g. aquatic plants)</li> <li>• Continuum of wetland types from lacustrine to palustrine, at varying stages of filling and drying which may or may not relate to seasonal fluctuations</li> <li>• Fire (particularly in peat areas)</li> <li>• Ecosystem services <ul style="list-style-type: none"> <li>o Significant number are related to connectivity across water bodies e.g. fish migration (fish breeding area)</li> <li>o Filtering</li> <li>o Sediment retention</li> <li>o Material flux/balance/polishing</li> </ul> </li> </ul>                                                                                                                                                                                                                                                                                                 |
| <ul style="list-style-type: none"> <li>• Need to define how long a dry area remains a wetland</li> <li>• Soil conditions (acid sulfate soils); Peat condition</li> <li>• Salt water intrusion</li> <li>• Biogeochemical cycling of nitrogen, phosphorus and carbon</li> <li>• Flooding</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |

**Drivers**

- Hydrological regime, periodicity of inundation, seasonal drawdown
- Fire
- Connectivity/barriers
- Sea level rise
- Feral animals
- Water quality
  - o Salinity
  - o Temperature
- Weeds

**Pressures**

- Fire
- Grazing
- Climate change
- Drainage
- Hydrology changes
- Hydrological regime

**Potential Indicators**

- Extent and structure of groundcover (vegetation health index) <sup>1</sup>
- Benthic biota
- Fish kills
- Organic loading
- Flow rate in bores and springs
- Extent
- Vegetation change
- Fauna habitat
- Diversity and abundance of the fauna
- Critical life stages
- Health of trees/cover (die back)

**Knowledge Gap**

- Extraction, discharge and recharge

<sup>1</sup> There is a possibility of using established vegetation indicators. It was noted that there is a lack of similar tools for sedgeland, shrublands, grassmats if using these indicators

## 9 Lacustrine and Palustrine Wetlands

Figure 15. Palustrine wetland (wet phase) conceptual model.

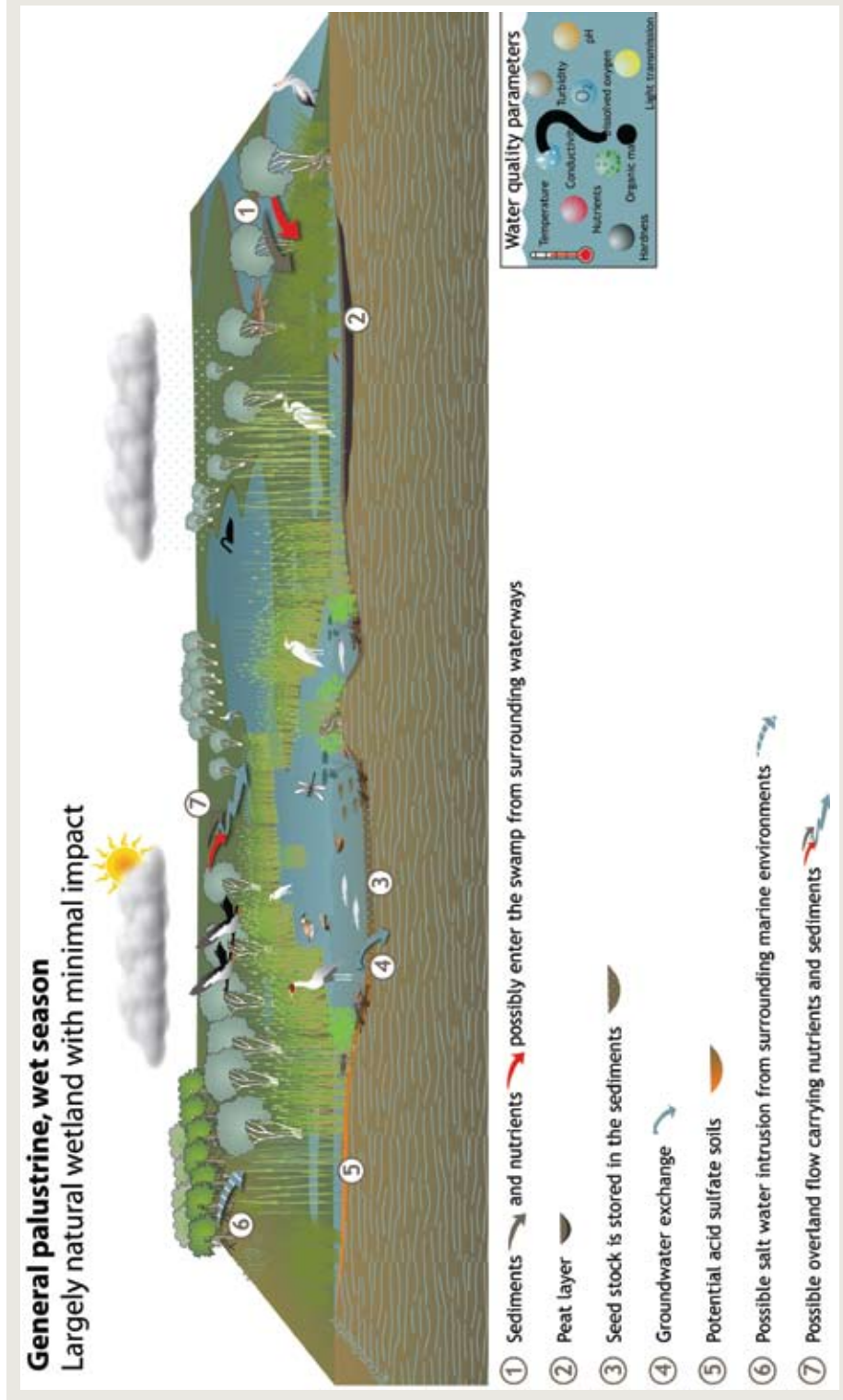
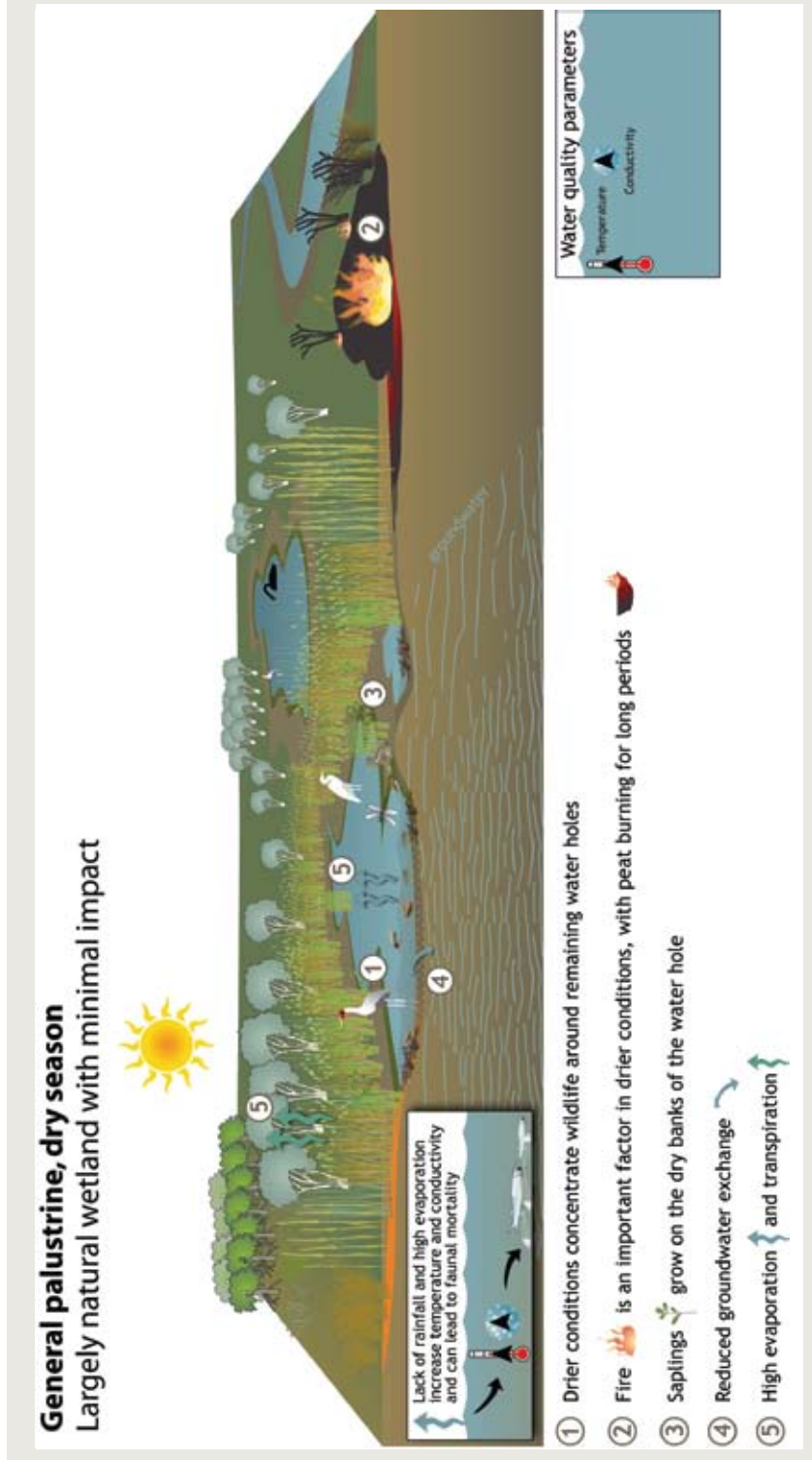


Figure 16. Palustrine wetland (dry phase) conceptual model.



# 9 Lacustrine and Palustrine Wetlands

**Table 53. Conceptual model for coastal forest swamps.**

| Coastal forest swamps e.g. Melaleuca, Casuarina                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p><b>Key Features</b></p> <p><b>Physical</b></p> <ul style="list-style-type: none"> <li>• Shallow</li> <li>• Seasonal inundation</li> <li>• Located <ul style="list-style-type: none"> <li>o Behind backdunes and saltmarsh</li> <li>o Depressions near rivers and estuaries</li> <li>o Floodplain depressions</li> <li>o Poorly drained lowland</li> </ul> </li> <li>• Can have old creek channels and deep holes</li> <li>• Bed can be impermeable, excluding groundwater exchange</li> <li>• Has a peat layer</li> </ul> <p><b>Hydrology</b></p> <ul style="list-style-type: none"> <li>• With/without groundwater inputs</li> <li>• Short drying phase</li> <li>• Source: overland flow</li> </ul> <p><b>Physico-chemical</b></p> <ul style="list-style-type: none"> <li>• Nutrients cycling important</li> <li>• Acid sulfate soils</li> <li>• Saline ground water</li> <li>• Influence of high spring tides/flooding</li> </ul> <p><b>Biota</b></p> <ul style="list-style-type: none"> <li>• Dominated by trees</li> <li>• Good biodiversity (fish, birds, mosquitoes, frogs, reptiles, mammals, insects)</li> <li>• Melaleucas: <ul style="list-style-type: none"> <li>o Rich source of pollen and nectar for local and migratory birds, insects, bats and possums</li> </ul> </li> <li>• Koalas feed on leaves <ul style="list-style-type: none"> <li>o Important refuges in drought</li> </ul> </li> <li>• Understorey can be variable – dependant on <ul style="list-style-type: none"> <li>o Water depth</li> <li>o Canopy cover</li> <li>o Water quality</li> <li>o Groundwater</li> <li>o pH</li> <li>o Salinity</li> <li>o Phragmites if saline; Blechnum fern if more freshwater</li> </ul> </li> </ul> |

**Processes**

- Fire
- Hydrological regime: flow, water depth, duration, (seasonally variable)
- Return flows back to river – providing nutrients, colour
- Flood attenuation, water filtering
- Fish habitat, fish nursery areas

**Drivers**

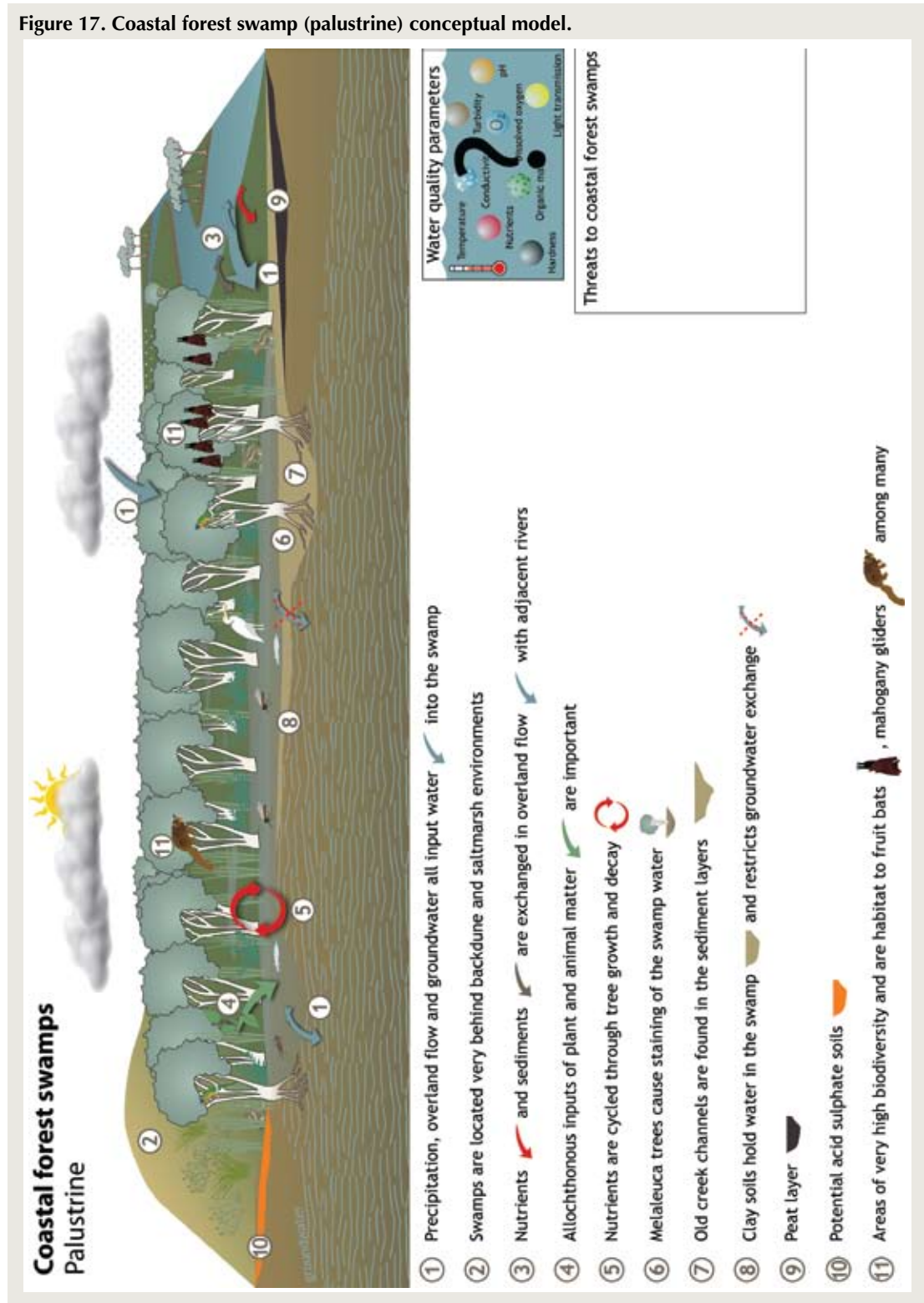
- Hydrology (hydroperiod – extent and frequency of inundation)
- Water depth
- Fire
- Water quality
  - Salinity
  - pH

**Pressures**

- Clearing
- Draining
- Grazing
- Acid sulfate soils
- Bark removal
- Fire (frequency and intensity)
- Weed invasion
- Channelisation of meanders in creeks
- Saline intrusion
- Rising sea levels

# 9 Lacustrine and Palustrine Wetlands

Figure 17. Coastal forest swamp (palustrine) conceptual model.



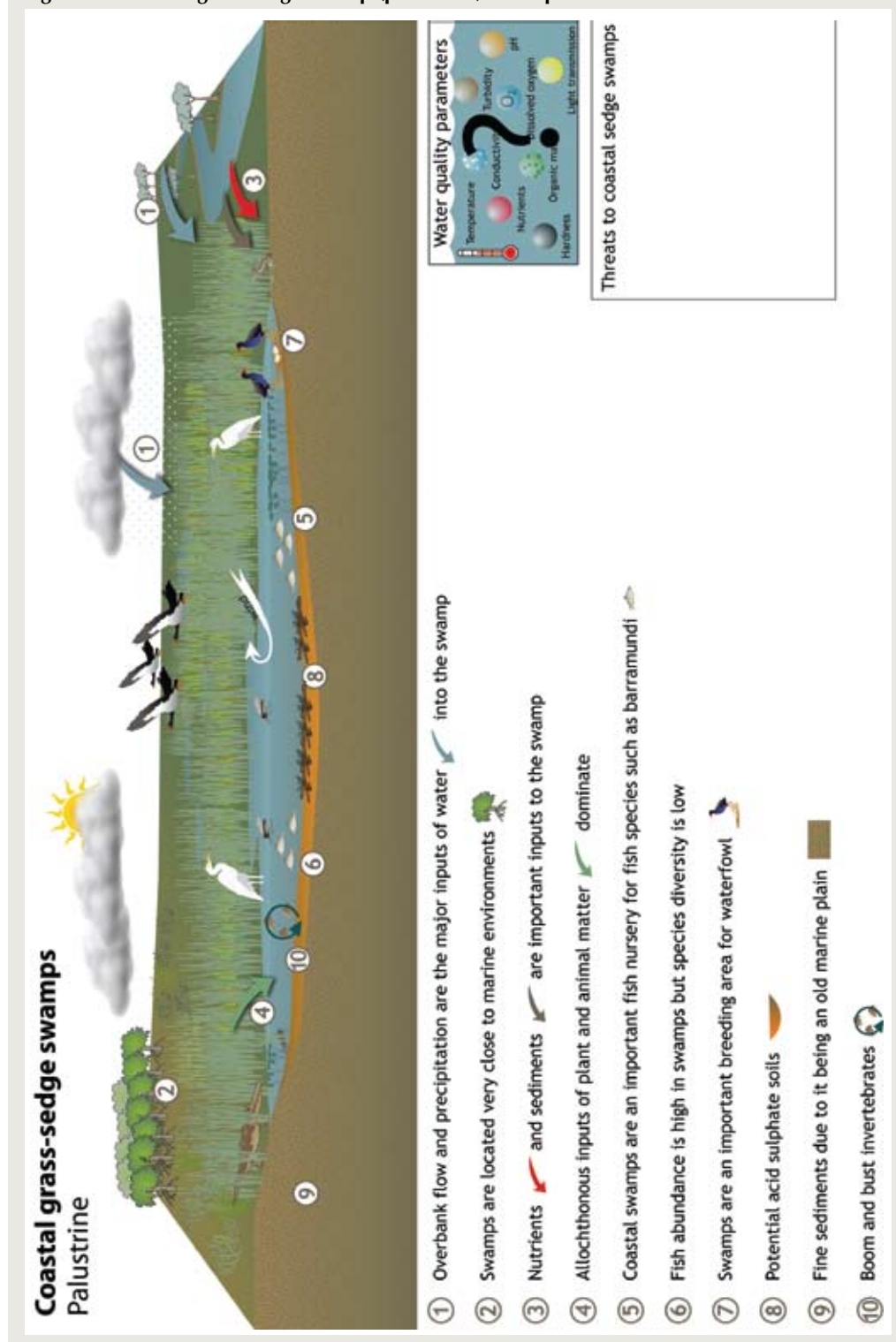
**Table 54. Conceptual model for coastal grass-sedge swamps.**

| Coastal grass-sedge swamps e.g. Bulkuru sedge                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p><b>Key Features</b></p> <p><b>Physical</b></p> <ul style="list-style-type: none"> <li>• Large waterbodies (100-1000 ha)</li> <li>• Old marine plains</li> <li>• Fine sediments</li> </ul> <p><b>Hydrology</b></p> <ul style="list-style-type: none"> <li>• Marine influenced</li> <li>• Source: local catchment, overbank flow</li> <li>• Rarely groundwater exchange</li> <li>• Seasonal drawdown to drying in some</li> </ul> <p><b>Physico-chemical</b></p> <ul style="list-style-type: none"> <li>• Potential acid sulfate soils</li> </ul> <p><b>Biota</b></p> <ul style="list-style-type: none"> <li>• Treeless</li> <li>• Emergent and aquatic macrophytes</li> <li>• Allochthonous dominated</li> <li>• Low number of fish species, high abundance</li> <li>• Seasonally highly productive – invertebrates are boom and bust</li> <li>• Has breeding aggregations (waterbirds)</li> <li>• Fish nursery</li> </ul> |
| <p><b>Drivers</b></p> <ul style="list-style-type: none"> <li>• Hydrology</li> <li>• Climate</li> <li>• Rainfall</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| <p><b>Pressures</b></p> <ul style="list-style-type: none"> <li>• Grazing</li> <li>• Weeds</li> <li>• Fire</li> <li>• Connectivity (bunding)</li> <li>• Tail-water inputs</li> <li>• Sediment loads</li> <li>• Climate change</li> <li>• Feral animals (pigs)</li> <li>• Organic loading by excess growth of grasses drying dry phase</li> <li>• Poned pastures (with/without bunding)</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |

# 9 Lacustrine and Palustrine Wetlands

Table 15 continued from previous page

Figure 18. Coastal grass-sedge swamp (palustrine) conceptual model.



**Table 55. Conceptual model for inland arid-zone swamps.**

| Inland arid-zone swamps (extensive in channel country)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Key Features</b><br><b>Physical</b> <ul style="list-style-type: none"> <li>• Geomorphology: variable size and shape</li> <li>• Shallow</li> <li>• Defined by vegetation (may also be bare e.g. claypans) <ul style="list-style-type: none"> <li>o Shrub: lignum</li> <li>o Grass: cane grass</li> <li>o Wooded: Coolibah, River Red Gum, Black Box, Casuarina</li> </ul> </li> </ul> <b>Hydrology</b> <ul style="list-style-type: none"> <li>• Sources: precipitation and local catchment (all types), overbank flow (Shrub, Wooded)</li> <li>• No groundwater interaction</li> </ul> <b>Physico-chemical</b> <ul style="list-style-type: none"> <li>• Variable turbidity</li> </ul> <b>Biota</b> <ul style="list-style-type: none"> <li>• Lignum swamps important for waterbirds</li> <li>• Boom and bust (invertebrates)</li> <li>• Important habitat for terrestrial grazers and stock when dry</li> </ul> |
| <b>Drivers</b> <ul style="list-style-type: none"> <li>• Climate (evaporation)</li> <li>• Soil type</li> <li>• Connection/isolation from river</li> <li>• Fire</li> <li>• Water quality</li> <li>• Water depth</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| <b>Pressures</b> <ul style="list-style-type: none"> <li>• Grazing (unsustainable)</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| <b>Impacts</b> <ul style="list-style-type: none"> <li>• Selective removal of vegetation by stock</li> <li>• Soil compaction, pugging</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| <b>Responses</b> <ul style="list-style-type: none"> <li>• Long term changes to vegetation (structure, recruitment, composition)</li> <li>• Loss of fauna habitat leading to reduced recruitment/nesting</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |

continued on next page

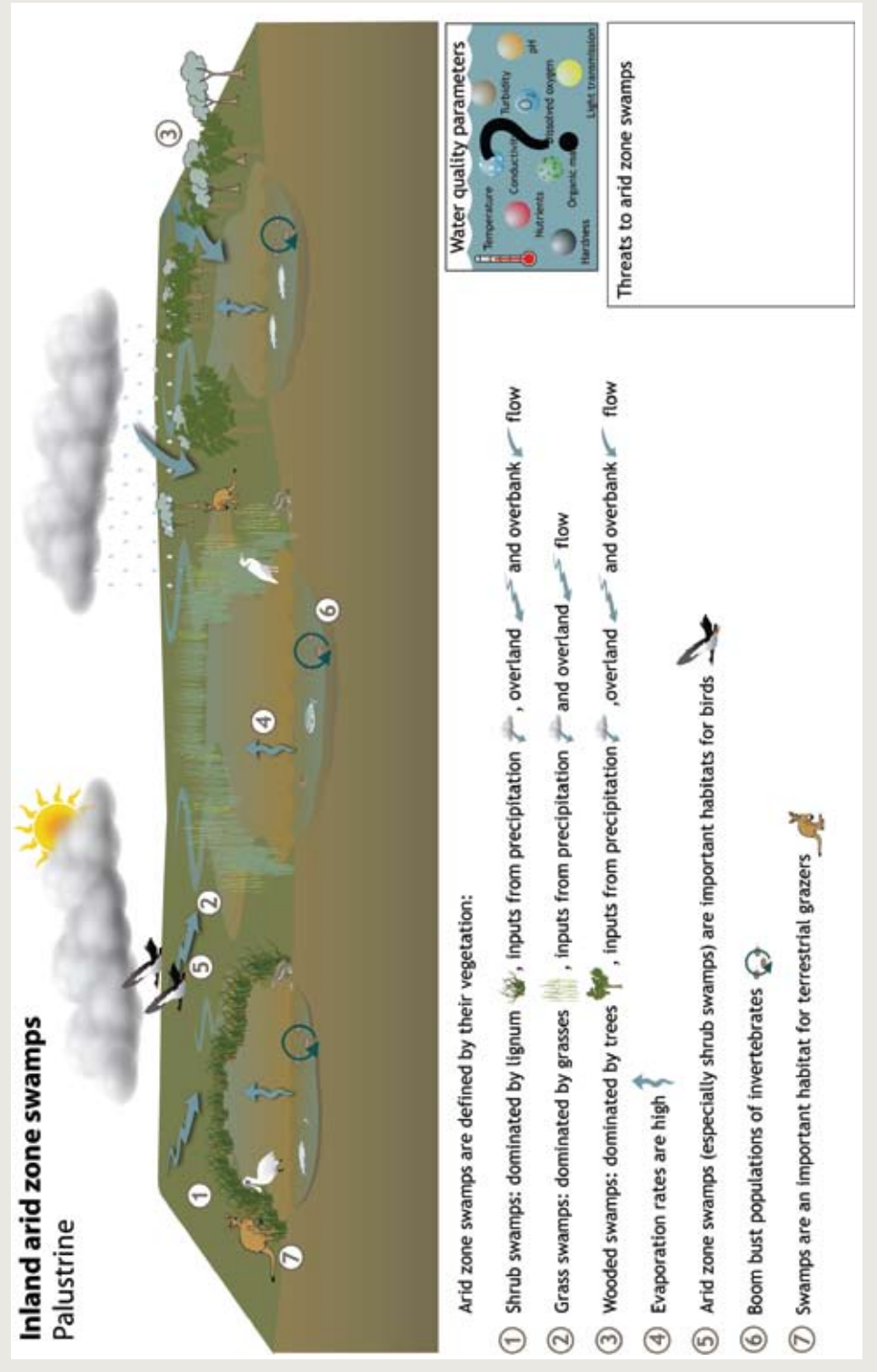
## 9 Lacustrine and Palustrine Wetlands

Table 55 continued from previous page

### Indicators

- Vegetative cover (on-ground; remote sensing not appropriate)
- Presence/absence of seedlings (giving a health index for vegetation)
- Pug density (stock rates)
- Stock track density
- Stocking rates (stock specific)
- Impact of native animals (how do we distinguish impacts from livestock?)
- Presence/absence of palatable species

Figure 19. Inland arid zone swamp (palustrine) conceptual model.

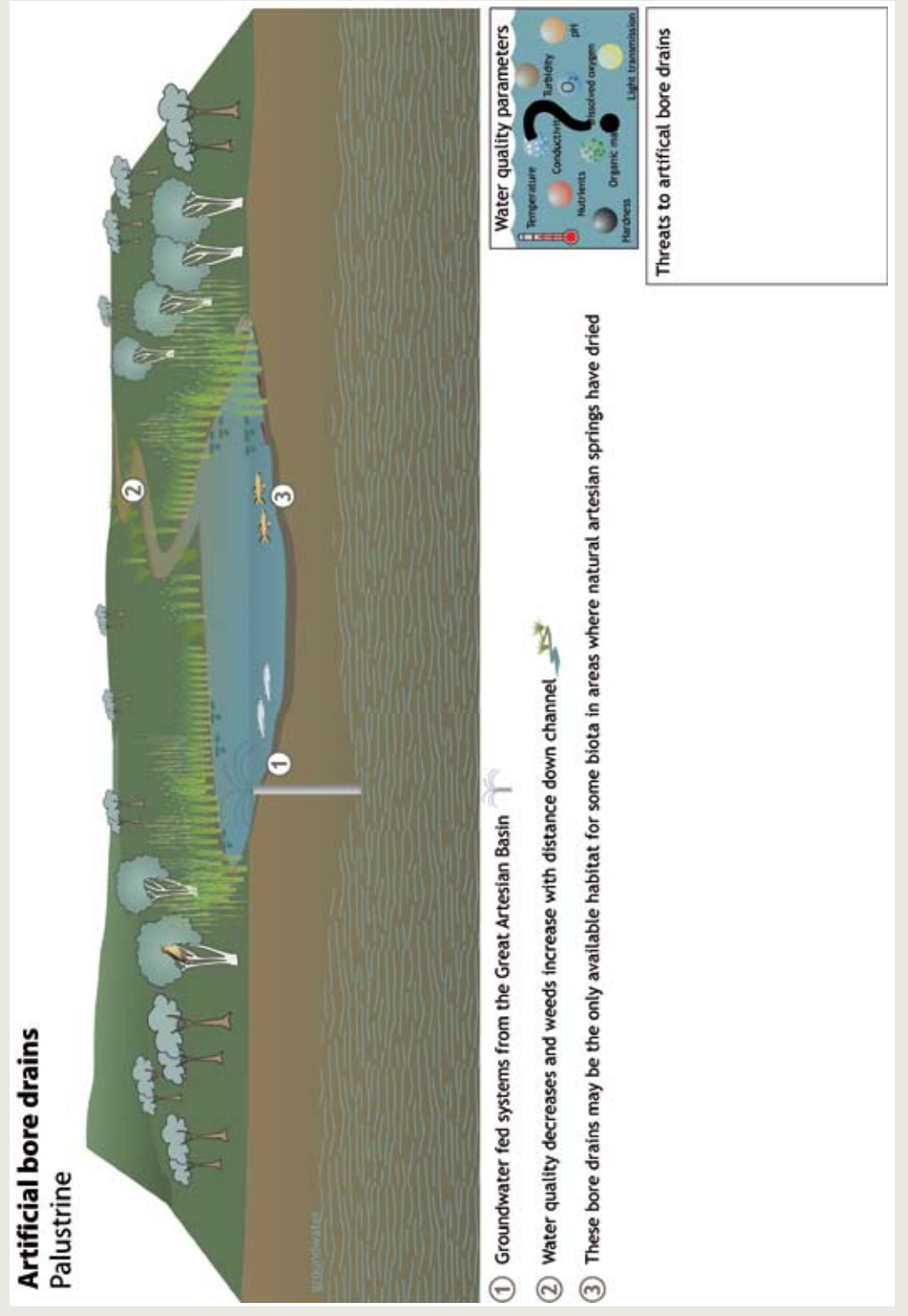


# 9 Lacustrine and Palustrine Wetlands

**Table 56. Conceptual model for artificial swamps (bore drains).**

| Artificial swamps (bore drains) |                                                                                                                                                                                                                                                                             |
|---------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Key Features</b>             |                                                                                                                                                                                                                                                                             |
| <b>Physical</b>                 |                                                                                                                                                                                                                                                                             |
|                                 | <ul style="list-style-type: none"> <li>• 0-10 ha around the spring or bore head, and may include a long, narrow channel covering many kilometres</li> <li>• Groundwater (Great Artesian Basin (GAB)) fed systems of purpose-managed drainline</li> <li>• Refugia</li> </ul> |
| <b>Hydrology</b>                |                                                                                                                                                                                                                                                                             |
|                                 | <ul style="list-style-type: none"> <li>• Open water</li> <li>• Pond or pool on the surface</li> <li>• Water level constant</li> <li>• No drying phase</li> </ul>                                                                                                            |
| <b>Biota</b>                    |                                                                                                                                                                                                                                                                             |
|                                 | <ul style="list-style-type: none"> <li>• Floating macrophytes, emergent reeds, sedges</li> <li>• Surrounding vegetation often contains weeds/ferals</li> </ul>                                                                                                              |
| <b>Drivers</b>                  |                                                                                                                                                                                                                                                                             |
|                                 | <ul style="list-style-type: none"> <li>• May mimic natural systems</li> <li>• Water quality                             <ul style="list-style-type: none"> <li>◦ Temperature</li> <li>◦ Water chemistry</li> <li>◦ Salinity, calcium, sodium</li> </ul> </li> </ul>         |
| <b>Pressures</b>                |                                                                                                                                                                                                                                                                             |
|                                 | <ul style="list-style-type: none"> <li>• Cap and pipe program</li> <li>• Stock</li> <li>• Recreation</li> </ul>                                                                                                                                                             |
| <b>Impacts</b>                  |                                                                                                                                                                                                                                                                             |
|                                 | <ul style="list-style-type: none"> <li>• Change floodplain dynamics, flows, and sediment storage</li> <li>• Declining water quality in the tailwater</li> <li>• Reduced GAB water pressure</li> <li>• Cap and pipe program</li> </ul>                                       |
| <b>Indicators</b>               |                                                                                                                                                                                                                                                                             |
|                                 | <ul style="list-style-type: none"> <li>• Flow rate and pressure</li> <li>• Extent</li> <li>• Vegetation change (terrestrial and aquatic)</li> <li>• Bird, fish populations</li> <li>• Tourist visitation</li> </ul>                                                         |

Figure 20. Artificial swamps (bore drain) (palustrine) conceptual model.

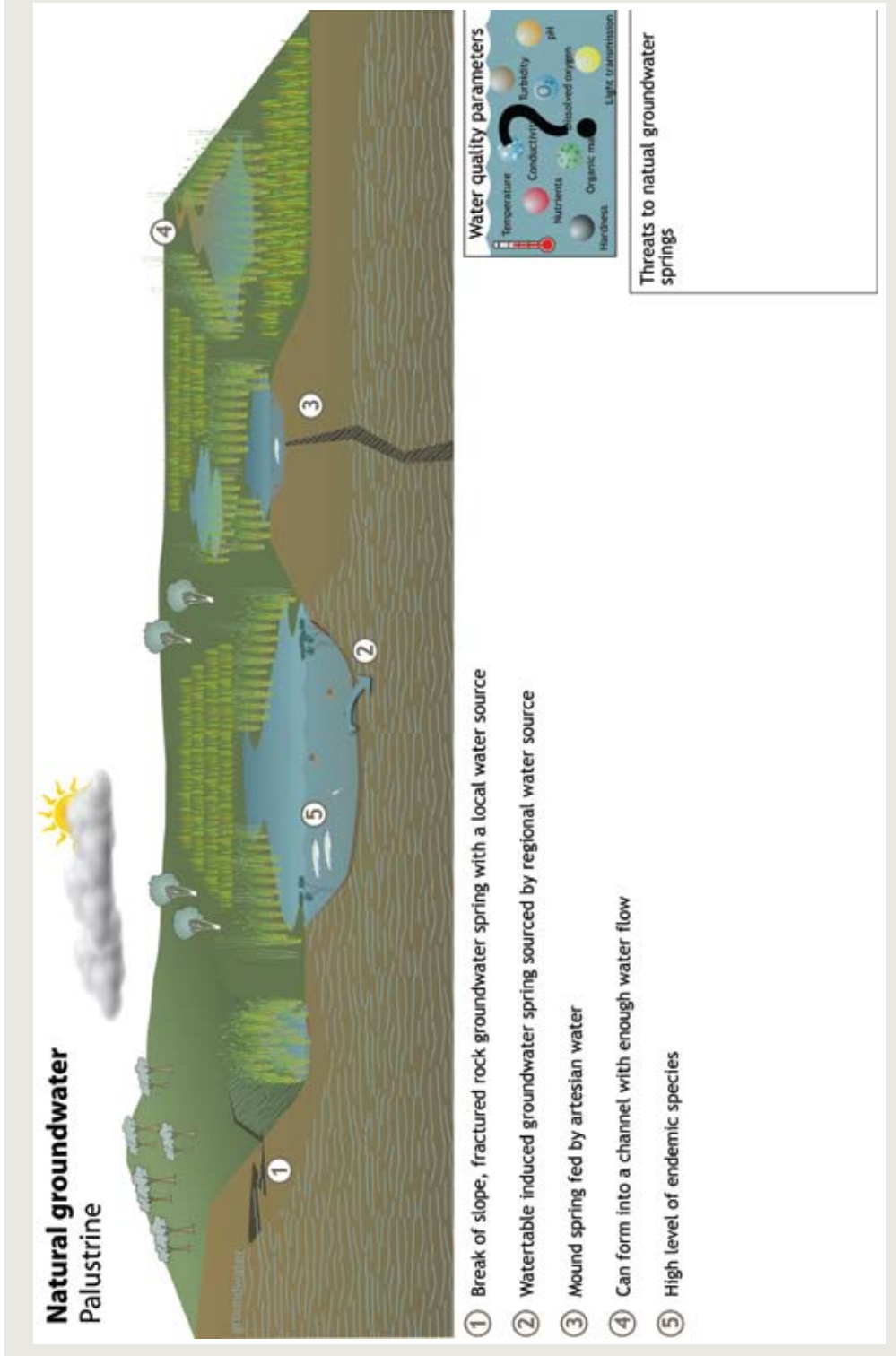


# 9 Lacustrine and Palustrine Wetlands

**Table 57. Conceptual model for natural groundwater springs.**

| Natural groundwater springs                                                                                                                                                                                                                                                                                                                                         |  |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--|
| <b>Key Features</b>                                                                                                                                                                                                                                                                                                                                                 |  |
| <i>Physical</i>                                                                                                                                                                                                                                                                                                                                                     |  |
| <ul style="list-style-type: none"> <li>• Generally isolated and localised systems</li> <li>• Different types                             <ul style="list-style-type: none"> <li>o Break of slope (fractured rock)</li> <li>o Watertable induced (due to fluctuations in groundwater)</li> <li>o Mound springs (mostly fed by artesian water)</li> </ul> </li> </ul> |  |
| <i>Hydrology</i>                                                                                                                                                                                                                                                                                                                                                    |  |
| <ul style="list-style-type: none"> <li>• Source:                             <ul style="list-style-type: none"> <li>o Break of slope: local catchment</li> <li>o Watertable induced: regional water</li> <li>o Mound springs: sub-artesian</li> </ul> </li> </ul>                                                                                                   |  |
| <i>Biota</i>                                                                                                                                                                                                                                                                                                                                                        |  |
| <ul style="list-style-type: none"> <li>• High level of endemic organisms (fish, crustacea, snails, invertebrates)</li> </ul>                                                                                                                                                                                                                                        |  |
| <b>Drivers</b>                                                                                                                                                                                                                                                                                                                                                      |  |
| <ul style="list-style-type: none"> <li>• Hydrology</li> <li>• Water quality</li> <li>• Extent and structure of vegetation</li> <li>• Extent of inundation area</li> </ul>                                                                                                                                                                                           |  |
| <b>Pressures</b>                                                                                                                                                                                                                                                                                                                                                    |  |
| <ul style="list-style-type: none"> <li>• Mound springs:                             <ul style="list-style-type: none"> <li>o Grazing (domestic, native, feral)</li> <li>o Agricultural development</li> <li>o Fire</li> <li>o Tourism</li> <li>o Drawdown (agricultural, mining)</li> <li>o Excavations and modifications</li> </ul> </li> </ul>                    |  |
| <b>Indicators</b>                                                                                                                                                                                                                                                                                                                                                   |  |
| <ul style="list-style-type: none"> <li>• Flow rate</li> <li>• Salinity (water quality)</li> <li>• Temperature</li> <li>• Flow extent/inundation area</li> <li>• Wetting/drying cycles</li> </ul>                                                                                                                                                                    |  |

Figure 21. Natural groundwater (palustrine) conceptual model.



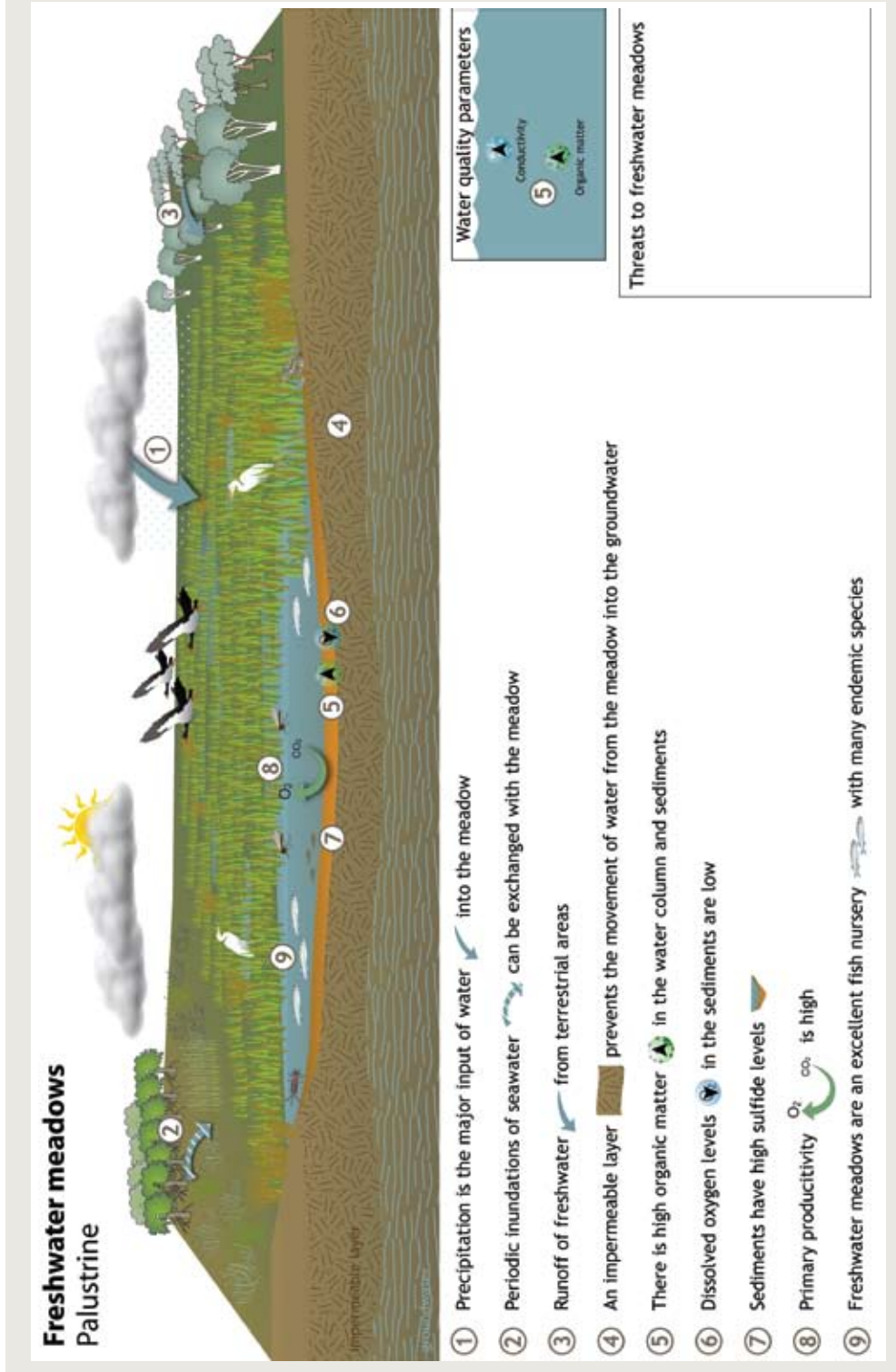
# 9 Lacustrine and Palustrine Wetlands

Freshwater meadows and herbs and forbs were developed separately at the workshop, but later discussion determined that the similarities were so great that they be treated as the one wetland type.

**Table 58. Conceptual model for freshwater meadows/herbs and forbs.**

| Freshwater meadows                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | Herbs and forbs                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p><b>Key Features</b></p> <p><b>Physical</b></p> <ul style="list-style-type: none"> <li>• Coastal, close to tidal influences</li> <li>• Similar to 'Herbs and Forbs'</li> <li>• &lt;0.5 m deep</li> </ul> <p><b>Hydrology</b></p> <ul style="list-style-type: none"> <li>• Exist as a result of water logging (groundwater)</li> <li>• Localised run-off</li> </ul> <p><b>Physico-chemical</b></p> <ul style="list-style-type: none"> <li>• Periodic inundation by salt water</li> <li>• High organic matter</li> <li>• Potential for acid sulfate soils</li> </ul> <p><b>Biota</b></p> <ul style="list-style-type: none"> <li>• Mangroves and saltmarsh nearby</li> <li>• Fish nursery</li> <li>• Uniform grass (herbs and forbs) growth</li> </ul> | <p><b>Key Features</b></p> <p><b>Physical</b></p> <ul style="list-style-type: none"> <li>• Small</li> <li>• Shallow (&lt;0.5 m deep)</li> <li>• Low relief</li> <li>• Clay/sand base</li> <li>• Seasonal/intermittent</li> </ul> <p><b>Hydrology</b></p> <ul style="list-style-type: none"> <li>• Source: precipitation</li> <li>• Generally no interaction with groundwater</li> </ul> <p><b>Physico-chemical</b></p> <ul style="list-style-type: none"> <li>• Freshwater</li> </ul> <p><b>Biota</b></p> <ul style="list-style-type: none"> <li>• Herb dominated, annuals</li> <li>• Turnover in species</li> <li>• Refugia from predation</li> </ul> |
| <p><b>Drivers</b></p> <ul style="list-style-type: none"> <li>• Hydrologic regime</li> <li>• Vegetation gradient (terrestrial to marine)</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | <ul style="list-style-type: none"> <li>• </li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| <p><b>Pressures</b></p> <ul style="list-style-type: none"> <li>• Human impact (people, urbanisation, grazing) <ul style="list-style-type: none"> <li>o Soil compaction</li> <li>o Plant loss</li> <li>o Nutrients increase</li> <li>o Increase in open water</li> <li>o Weeds</li> </ul> </li> <li>• Climate change (sea level rise)</li> <li>• Vegetation clearing</li> <li>• Cultivation</li> <li>• Fire</li> <li>• Poned pasture</li> </ul>                                                                                                                                                                                                                                                                                                        | <p><b>Pressures</b></p> <ul style="list-style-type: none"> <li>• Grazing and cutting</li> <li>• Pugging</li> <li>• Cropping and leveling</li> <li>• Weed invasion</li> <li>• Fire</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| <p><b>Indicators</b></p> <ul style="list-style-type: none"> <li>• Ground cover change and extent</li> <li>• Benthic biota</li> <li>• Fish kills</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | <p><b>Indicators</b></p> <ul style="list-style-type: none"> <li>• Vegetation assessment (wet and dry phases)</li> <li>• Weediness</li> <li>• Grazing pressure (remote sensing)</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                              |

Figure 22. Freshwater meadow/herbs and forbs (palustrine) conceptual model.



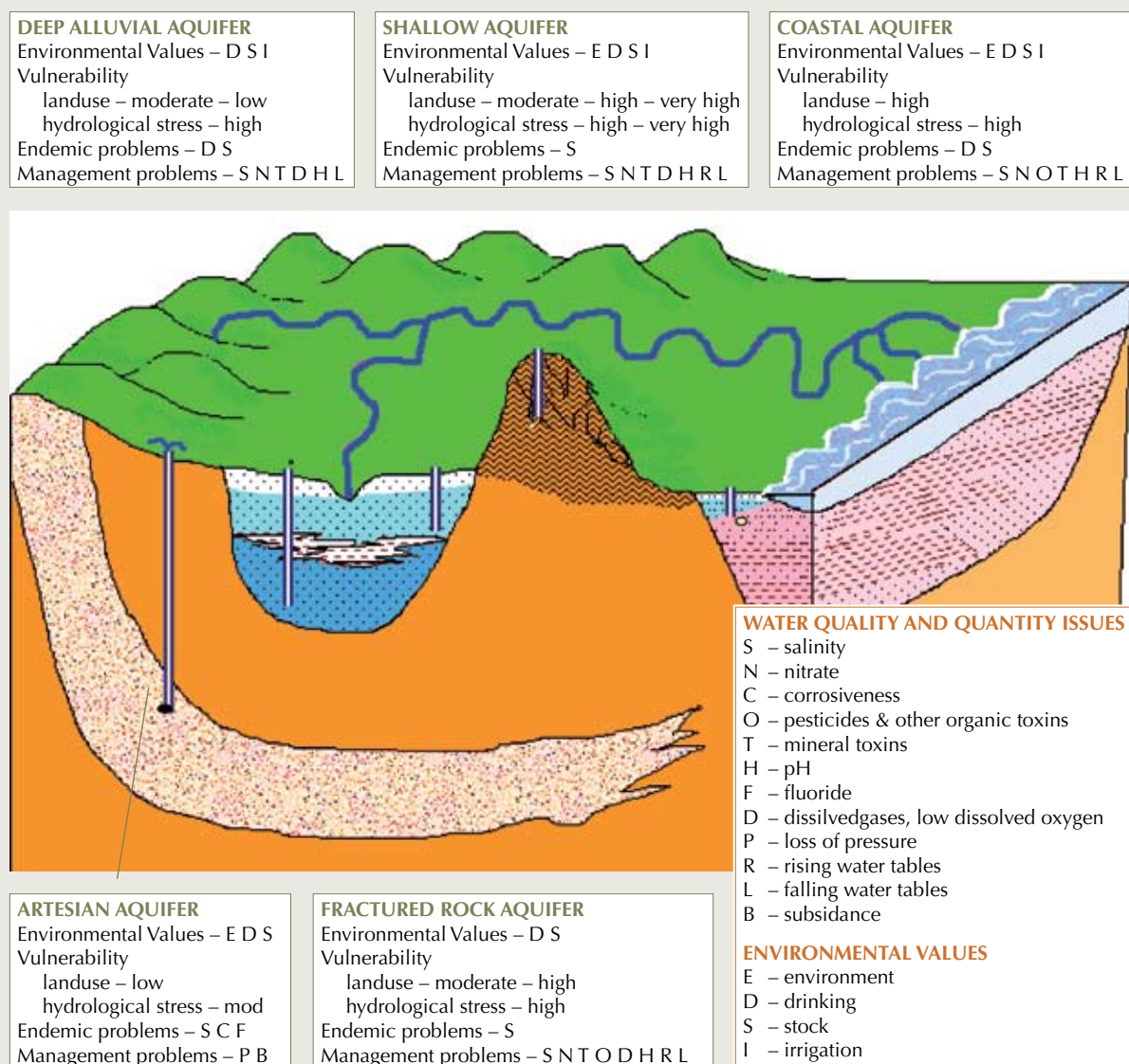
# 10 Groundwater Wetlands

Groundwater is a natural resource whose importance has only been widely recognised in the past few years. Increasing pressure placed on groundwater reserves through extraction and anthropogenic impacts has prompted governments and researchers to focus on the resource as an ecosystem deserving of understanding, protection and management. Groundwater dependent ecosystems (GDE) are those ecosystems that derive part or all of their aquatic resources from underground water. Researchers have recognised six categories of GDEs (terrestrial vegetation, river base flow systems, aquifer and cave

ecosystems, wetlands, terrestrial fauna, and estuarine and near-shore marine ecosystems) (Sinclair Knight Merz 2001), some of which have already been addressed in this report.

Queensland has an extensive groundwater aquifer system, part of which is the Great Artesian Basin. There are many other aquifers including coastal, alluvial (shallow and deep), and fractured rock (Figure 23), all of which are prone to differing stresses (Table 59) (McNeil & Clarke 2007).

**Figure 23. Characteristics of main aquifer types (McNeil & Clarke 2007).**



**Table 59. Water quality indicators for aquifer type (McNeil & Clarke 2007).**

| Aquifer Type                | Potential Environmental Values                                                                                             | Pressure                                                                                                                                                                            | Condition                                                                                                                                                                                               | Response                                                                                                                                                                                                                       |
|-----------------------------|----------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Shallow alluvial (... 30 m) | <ul style="list-style-type: none"> <li>• Environment</li> <li>• Drinking</li> <li>• Stock</li> <li>• Irrigation</li> </ul> | <ul style="list-style-type: none"> <li>• Land clearing</li> <li>• Development</li> <li>• Stream regulation and irrigation</li> <li>• Natural salinity</li> <li>• Overuse</li> </ul> | <ul style="list-style-type: none"> <li>• Salinity</li> <li>• Salinity trend</li> <li>• Sodium Adsorption Ratio (SAR)</li> <li>• Nitrates</li> <li>• Pesticides</li> </ul>                               | <ul style="list-style-type: none"> <li>• Actions to combat salinity</li> <li>• Control of pollutants in vulnerable areas</li> <li>• Improved management of irrigation supplies</li> </ul>                                      |
| Deep alluvial               | <ul style="list-style-type: none"> <li>• Drinking</li> <li>• Stock</li> <li>• Irrigation</li> </ul>                        | <ul style="list-style-type: none"> <li>• Stream regulation and irrigation</li> <li>• Natural salinity</li> <li>• Overuse</li> </ul>                                                 | <ul style="list-style-type: none"> <li>• Salinity</li> <li>• Salinity trend</li> <li>• Sodium Adsorption Ratio (SAR)</li> <li>• Corrosiveness, heavy metals and iron bacteria in the future.</li> </ul> | <ul style="list-style-type: none"> <li>• Avoidance of unsustainable use</li> <li>• Artificial recharge</li> <li>• Management of soil productivity decline</li> </ul>                                                           |
| Fractured Rock              | <ul style="list-style-type: none"> <li>• Drinking</li> <li>• Stock</li> <li>• Irrigation</li> </ul>                        | <ul style="list-style-type: none"> <li>• Land clearing</li> <li>• Development</li> <li>• Natural salinity</li> <li>• Overuse</li> </ul>                                             | <ul style="list-style-type: none"> <li>• Salinity</li> <li>• Sodium Adsorption Ratio (SAR)</li> <li>• Nitrates</li> </ul>                                                                               | <ul style="list-style-type: none"> <li>• Control of pollutants in vulnerable areas</li> <li>• Avoidance of unsustainable use</li> </ul>                                                                                        |
| Artesian                    | <ul style="list-style-type: none"> <li>• Drinking</li> <li>• Stock</li> <li>• Environment</li> </ul>                       | <ul style="list-style-type: none"> <li>• Overuse</li> <li>• Natural salinity, corrosiveness, fluorides, possibly heavy metals, high temperatures</li> </ul>                         | <ul style="list-style-type: none"> <li>• Salinity</li> <li>• Corrosiveness</li> <li>• Fluoride</li> </ul>                                                                                               | <ul style="list-style-type: none"> <li>• Avoidance of unsustainable use</li> <li>• Improved management of natural problems, ie replacement of corroded casings with more suitable types, dilution of high fluoride.</li> </ul> |
| Coastal                     | <ul style="list-style-type: none"> <li>• Environment</li> <li>• Drinking</li> <li>• Stock</li> <li>• Irrigation</li> </ul> | <ul style="list-style-type: none"> <li>• Land clearing</li> <li>• Overuse</li> <li>• Development</li> <li>• Salinity and low pH are main natural problems</li> </ul>                | <ul style="list-style-type: none"> <li>• Salinity</li> <li>• Sodium Adsorption Ratio (SAR)</li> <li>• Salinity trend</li> <li>• Nitrates</li> <li>• Corrosiveness</li> </ul>                            | <ul style="list-style-type: none"> <li>• Avoidance of unsustainable use</li> <li>• Control of pollutants in vulnerable areas</li> <li>• Avoid dewatering acid sulphate soils</li> </ul>                                        |

# 10 Groundwater Wetlands

The Wetland Indicators Workshop addressed groundwater as a separate topic, in order to gain an understanding of the special requirements of this unique ecosystem. It was recognised that the groundwater contribution to surface wetlands can often be considerable and progress is being made in an attempt to understand the functioning of these GDEs with respect to their groundwater components. Surface manifestations of underground water have been discussed earlier in this report (stream base flow, perched water tables, mound springs, groundwater exchange in some lakes). The workshop also developed a conceptual model for underground wetlands i.e. those wetlands without surface breakout (Table 60).

Within Queensland, NRW has approximately 5000 bores, the majority of which are sited in the east coast basins in subartesian aquifers i.e. where water must be pumped to the surface. Monitoring of bores is undertaken by NRW regularly. Water levels are measured between weekly and quarterly, depending on the bore site and/or region. Water quality is measured on an annual or biannual basis. All sites are tested for general parameters including electrical conductivity, pH, hardness, alkalinity, TDS, anions and cations. Many bores are sampled for nutrients, and some for metals. Some bores in the coastal regions have also had conductivity profiles taken to

**Table 60. Conceptual model for underground wetlands.**

| Groundwater <i>(significant knowledge gaps exist)</i>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p><b>Key Features of underground wetlands i.e. wetlands without surface breakout</b></p> <p><b>Physical</b></p> <ul style="list-style-type: none"> <li>• Different types of underground wetlands <ul style="list-style-type: none"> <li>◦ Subterranean karst</li> <li>◦ Fractured rock</li> <li>◦ Alluvial hyporheic (the wetted interstitial zone among sediments below and alongside rivers)</li> </ul> </li> <li>• Porous</li> </ul> <p><b>Biota</b></p> <ul style="list-style-type: none"> <li>• Low species richness</li> <li>• Unique biota (stygo fauna – fauna that live within groundwater systems)</li> <li>• Some species are ancient surface species</li> </ul> |
| <p><b>Processes</b></p> <ul style="list-style-type: none"> <li>• Provides wildlife refuge where it is a break out feature e.g. bird habitat</li> <li>• Denitrification</li> <li>• Nutrient transfer (rivers)</li> <li>• Filters contaminants before delivery to groundwater/surface water</li> </ul>                                                                                                                                                                                                                                                                                                                                                                         |
| <p><b>Pressures</b></p> <ul style="list-style-type: none"> <li>• Water extraction influences the maintenance of supplies</li> <li>• Seawater intrusion leading to impacts on the stygo fauna and reduction of porosity</li> <li>• Chemical pollution</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                              |
| <p><b>Indicators</b></p> <ul style="list-style-type: none"> <li>• Groundwater regime</li> <li>• Water quality (saline pollution)</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |

monitor salt-water intrusion. NRW has approximately 400 bores in the Great Artesian Basin, a selection of which are measured each year for flows as well as the standard water quality parameters.

In addition to the regular departmental bores there are also 448 salinity bores that were drilled for the NAP program. Regular monitoring was undertaken during the NAP, but their monitoring status is unknown at present. They are not currently in the departmental monitoring network.

All this data is stored on the NRW Groundwater Database which holds information on approximately 130,000 bore sites. The majority of these sites are privately owned although not all the bores are currently active. When a bore is drilled (NRW or private), water level and field water quality measurements are taken and the data is stored on the NRW database. No further information is collected on private bores, except under unusual circumstances.

Investigation of groundwater ecosystems is gradually gaining momentum in Australia (Hancock & Steward 2004). In Queensland, some monitoring work has been undertaken by NRW on the hyperheic and parafluvial zones, and bores in selected catchments by NRW. Standing water levels, and water quality parameters (electrical conductivity, pH, dissolved oxygen, redox potential, temperature, alkalinity, turbidity, pesticides, nutrients) were measured. Stygofauna and bacteria samples were also collected.

Recently an investigation into the GDEs of Stradbroke Island commenced in response to a proposal to expand the bore fields used for extraction of water to supplement water supplies on the nearby mainland. Parameters measured include biota (macroinvertebrates, fish, macrophytes, vegetation), depth, electrical conductivity, saltwater intrusion on monitoring bores and core sampling to determine the evolutionary significance of potential depth drops.

# 11 Recommendations

One of the major outcomes of this project was to be a set of recommendations to inform the national review of the Matters for Target wetland indicators. As the national project is nearing completion at the same time as this project, that outcome has become somewhat obsolete. In its stead, the knowledge and information that has been gained from this project has been used to inform the national indicators project, including:

- The literature search was modified for use in the national workshop background report and incorporated into the final report, and
- The wetland classification work provided the basis for the 'Wetland Description Tool' which was delivered to the jurisdictional workshops for comment and modification.

The conceptual models that were developed in the Wetland Indicators workshop were selected intuitively, rather than by any methodical selection process. Part of the reason for this was the absence of any agreed classification system for wetlands in Queensland. Both the National Wetland Indicators project and this project see a need to develop conceptual models for all wetland types. As different pressures and stressors operate in different wetland types, this will provide a basis for understanding different wetlands and, therefore, the selection of appropriate indicators for monitoring condition. Models have been developed using pressure, stressor, response models for estuarine systems (OzEstuaries and SEAP) and are under development for bioprovincial riverine systems in Queensland (SEAP). This project recommends that the lacustrine and palustrine conceptual models be reviewed and redeveloped using the recommended classification system.

In developing the monitoring framework, one of the many points stressed was that alternative methods should be developed for application to all skill levels. This would then engage all stakeholders from community level, with relatively limited capabilities in more complex indicators, researchers, and all levels of government. This may be possible for some indicators, but it quickly became apparent that, for other indicators, this will not be possible. There are indicators that community groups or NRM regional bodies will not have the fiscal or physical resources to monitor e.g. remote sensing for both extent and

distribution, and condition. And there are some indicators that require products such as remote sensing layers that are beyond the scope of State agency purchasing power, but may be available at a national level. This project recommends that all levels of government, researchers and regional/community groups liaise closely to enhance wetland extent, distribution and condition monitoring e.g. common remote sensing layers be provided to State agencies for mapping and condition monitoring which is provided to NRM regional bodies for use in their regions; relevant State agency monitoring information be provided to NRM bodies.

This report has presented detailed information on indicators that are in use or are proposed for assessment or monitoring. It has become apparent that the selection of indicators needs to be a purpose driven exercise, and to prescribe a set of indicators in this document for monitoring could invite failure in the program to deliver accurate assessments. It is recommended that the information provided here be a starting point for selecting indicators, that conceptual models of the system under investigation be developed, and appropriate indicators be selected on the basis of purpose, scale, cost, and skill.

# 12 References

- Abal, E.G., Bunn, S.E., and Dennison, W.C. (Eds) (2005). Healthy waterways, healthy catchments: making the connection in south east Queensland, Australia. Moreton Bay Waterways and Catchments Partnership. Queensland, Australia.
- Anderson, J.R. (1993). *State of the Rivers Project: Report 1. Development and validation of the methodology*. Department of Primary Industries Queensland; Brisbane
- ANZECC (Australian and New Zealand Environment and Conservation Council), State of the Environment Reporting Task Force (2000). *Core Environmental Indicators for Reporting on the State of the Environment*. Environment Australia, Canberra.
- ANZECC & ARMCANZ (2000). Australian guidelines for water quality monitoring and reporting. Australia and New Zealand Environment and Conservation Council (ANZECC) and Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ), National Water Quality Management Strategy No. 7, Canberra.
- Baldwin, D.S., Nielson, D.L., Bowen, P.M., and Williams, J. (2005). Recommended Methods for Monitoring Floodplains and Wetlands. MDBC Publication No. 72/04. Murray-Darling Basin Commission, Canberra, and Murray Darling Freshwater Research Centre, Albury.
- Blackman, J.G., Spain, A.V., and Whiteley, L.A. (1992). Provisional handbook for the classification and field assessment of Queensland's wetlands and deepwater habitats. Environmental Protection Agency, Queensland.
- Boulton, A.J., and Brock, M.A. (1999). *Australian Freshwater Ecology. Processes and Management*. CRC Freshwater Ecology. Gleneagles Publishing, Adelaide.
- Brierley, G., Fryirs, K., and Cohen, T. (1996). Development of a generic geomorphic framework to assess catchment character. Part 1. A geomorphic approach to catchment characterisation. Working Paper 9603, Macquarie University, Graduate School of the Environment.
- Brierley, G.J., and Fryirs, K.A. (2005). *Geomorphology and River Management: Application of the River Styles Framework*. Blackwell Publications, Oxford, UK. 398pp
- Brierley, G.J., Fryirs, K., Outhet, D., and Massey, C. (2002). Application of the River Styles framework to river management programs in New South Wales, Australia. *Applied Geography* **22**:91-122.
- Brinson, M. M. (1993). *A hydrogeomorphic classification for wetlands*. Technical Report WRP-DE-4, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.
- Butcher, R. (2003). Options for the assessment and monitoring of wetland condition in Victoria. The State of Victoria, State Water Quality Monitoring and Assessment Committee.
- Casanova, M.T. (1999). Plant establishment in Paroo wetlands: The importance of water regime. In 'A free-flowing river: The ecology of the Paroo River.' (Ed. R. Kingsford). National Parks and Wildlife Service, NSW.
- CBD Secretariat/Ramsar Convention Secretariat (2006). *Guidelines for the rapid assessment of biodiversity in inland water, coastal and marine areas*. CBD technical Series No. 22 / Ramsar Technical report No. 1. Secretariat of the Convention on Biological Diversity (Quebec, Canada); Secretariat of the Convention on Wetlands (Ramsar, Iran, 1971) (Switzerland.).
- Chessman, B.C., Growns, J.E., and Kotlash, A.R. (1997). Objective derivation of macroinvertebrate family sensitivity grade numbers for the SIGNAL biotic index: application to the Hunter River system, New South Wales. *Marine and Freshwater Research* **48**:159-172.
- Chessman, B.C., Trayler, K.M., and Davis, J.A. (2002). Family- and species-level biotic indices for macroinvertebrates of wetlands on the Swan Coastal Plain, Western Australia. *Marine and Freshwater Research* **53**(5): 919 – 930.
- Chessman, B.C. (1995). Rapid assessment of rivers based on habitat-specific sampling, family level identification and a biotic index. *Australian Journal of Ecology* **20**:122-129.
- Chessman, B.C. (2003). *SIGNAL 2.iv. A Scoring System for Macro-Invertebrates ('Water Bugs') in Australian Rivers*, User manual Version 2. Accessed from <http://www.deh.gov.au/water/rivers/nrhp/signal/index.html>.

# 12 References

- Clarkson B.R., Sorrell B.K., Reeves P.N., Champion P.D., Partridge T.R., and Clarkson B.D. (2004). *Handbook for monitoring wetland condition (Revised October 2004) Coordinated Monitoring of New Zealand Wetlands*. A Ministry for the Environment Sustainable Management Fund Project (5105).
- Clayton, P.D., Fielder, D.P., Howell, S., and Hill, C.J. (2006). *Aquatic Biodiversity Assessment and Mapping Method (AquaBAMM): a conservation values assessment tool for wetlands with trial application in the Burnett River catchment*. Environmental Protection Agency, Brisbane.
- Conrick, D. (2005). *Monitoring, Evaluation and Reporting Strategy for the Queensland Wetlands Programme*. Natural Resources and Mines, Brisbane.
- Conrick, D., Edgar, B., and Innes, A. (2007). *Development of National Indicators for Wetland Ecosystem Extent, Distribution and Condition. Final Report*. NLWRA, Canberra.
- Corrick, A.H., and Norman, F.I. (1980). Wetlands of Victoria I. Wetlands and waterbirds of the Snowy River and Gippsland Lakes catchment. *Proceedings of the Royal Society of Victoria* **91**:1-15.
- Cowardin, L.M., Carter, V., Golet, F.C., and LaRoe, E. T. (1979). *Classification of wetlands and deepwater habitats of the United States*. U.S. Department of the Interior, Fish and Wildlife Service, Washington, D.C. 131pp.
- Davis, J., Horwitz, P., Norris, R., and Chessman, B. (2001). *Monitoring Wetland Health: Are National River Health Program Protocols Applicable? Final Report*. Report prepared for National Wetlands Research and Development Program, Canberra. Accessed from <http://www.deh.gov.au/water/wetlands/rd/monitor/>
- Davis, J., Horwitz, P., Norris, R., Chessman, B., McGuire, M., and Sommer, B. (2006). Are River Bioassessment Methods using Macroinvertebrates Applicable to Wetlands? *Hydrobiologia* **572(1)**:115-128.
- Davis, J., Horwitz, P., Norris, R., Chessman, B., McGuire, M., Sommer, B., and Trayler, K.M. (1999). *Monitoring Wetland Health: are National River Health Program protocols applicable? Wetland Bioassessment Manual*. Report prepared for National Wetlands Research and Development Program, Canberra.
- Dixon, I., Douglas, M., Dowe, J., & Burrows, D. (2006). *Tropical Rapid Appraisal of Riparian Condition Version 1 (for use in tropical savannas)*. River Management Technical Guideline No. 7. Land & Water Australia, Canberra.
- DSE (2005a). *Index of Stream Condition: The Second Benchmark of Victorian River Condition*. Department of Sustainability and Environment, Victoria.
- DSE (2005b). *Index of Wetland Condition. Conceptual framework and selection of measures*. Department of Sustainability and Environment, Victoria.
- DSE (2006). *Index of Wetland Condition. Review of wetland assessment methods*. Department of Sustainability and Environment, Victoria.
- Duguid, A., Barnetson, J., Clifford, B., Pavey, C., Albrecht, D., Risler, J., and McNellie, M. (2002). *Wetlands in the arid Northern Territory. A report to Environment Australia on the inventory and significance of wetlands in the arid NT*. Parks and Wildlife Commission of the Northern Territory. Alice Springs.
- Duke, N.C., Lawn, P.T., Roelfsema, C.M., Phinn, S., Zahmel, K.N., Pedersen, D.K., Harris, C., Steggle, N., and Tack, C. (2003). *Assessing historical change in coastal environments. Port Curtis, Fitzroy River estuary and Moreton Bay regions*. Final Report to the CRC for Coastal Zone Estuary & Waterway Management. Historical Coastlines Project, Marine Botany Group, Centre for Marine Studies, The University of Queensland, Brisbane. 258 pages. <http://www.coastal.crc.org.au/Publications/HistoricalCoastlines.html>
- EHMP marine and estuarine program: [http://www.ehmp.org/estuarinemarine\\_monitoring.html](http://www.ehmp.org/estuarinemarine_monitoring.html) accessed 30.5.07
- Environment Australia (2001). *A Directory of Important Wetlands in Australia, Third Edition*. Environment Australia, Canberra.
- EPA (1999). *Water Quality Sampling Manual*. 3<sup>rd</sup> Edition. EPA, Brisbane.

EPA (2005a). SoE Online. Supporting information for contributing Queensland Government officers. EPA, Queensland.

EPA (2005b). *Wetland Mapping and Classification Methodology. Overall Framework. A method to provide baseline mapping and classification for wetlands in Queensland. Version 1.2.* Queensland Government, Brisbane.

Fabricius, K., Uthicke, S., Humphrey, C., Cooper, T., and De'ath, G. (draft-28<sup>th</sup> March 2007). *Potential water quality specific indicators for the reef Water Quality Protection Plan monitoring of estuaries and inshore coral reefs: Summary and overview of benefits and costs.* MTSRF, Townsville.

Fennessy, M.S., Jacobs, A.D., & Kentula, M.E. (2004) Review of rapid methods for assessing wetland condition. EPA/620/R-04/009. U.S. Environmental Protection Agency, Washington, D.C.

Finlayson, C.M., Grazia Bellio, M., and Lowry, J.B. (2005). A conceptual basis for the wise use of wetlands in northern Australia – linking information needs, integrated analyses, drivers of change and human well-being. *Marine and Freshwater Research* **56**:269-277.

Golus, C., Burns, C., and Westlake, M. (2006). *Wetland Assessment Technique. Version 3.1.* WetlandCare Australia. Ballina, Australia.

Green D.L. (1997). Wetland Classification. Ecological Services Unit. In. *NSW Wetland Management Policy – Management Guidelines.* (Ed. Department of Land and Water Conservation) Parramatta.

Grinter, S., and Clarke, R. (2006). Ambient surface water quality in Queensland 2002-2005. Summary report. Queensland Department of Natural Resources, Mines and Water, Indooroopilly.

Hancock, P., and Steward, A. (2004). *Pioneer groundwater biota pilot study. Review of sampling methods for groundwater fauna and bacteria.* Aquatic Ecosystems Technical Report No. 49. Natural Resources and Mines, Indooroopilly.

Healthy Reefs for Healthy People: Key Indicators [http://www.healthyreefs.org/indicators\\_key\\_indicator\\_introduction.html](http://www.healthyreefs.org/indicators_key_indicator_introduction.html)

Hill, A.L., Semeniuk, C.A., Semeniuk, V., and del Marco, A. (1996). *Wetlands of the Swan Coastal Plain. Volume 2a. Wetland Mapping, Classification and Evaluation, Main Report.* Water Authority of Western Australia and Department of Environmental Protection, Perth.

Jaensch, R. (1999). *The status and importance of south-west Queensland's wetlands.* Report by Wetlands International-Oceania to Environmental Protection Authority.

Jansen, A., Robertson, A., Thompson, L., and Wilson, A., (2005). *Rapid appraisal of riparian condition, version 2.* River Management Technical Guideline No. 4A. Land & Water Australia, Canberra.

Johnson, P., and Gerbeaux, P. (2004). *Wetland types in New Zealand.* Department of Conservation, New Zealand.

Kingsford, R.T., and Porter, J. (1999). Wetlands and waterbirds of the Paroo and Warrego rivers. In 'A free-flowing river: The ecology of the Paroo River.' (Ed. R. Kingsford). National Parks and Wildlife Service, NSW.

Ladson, A., and White, L. (1999). *Index of Stream Condition: reference manual.* Department of Natural Resources and Environment, Melbourne.

Langbein, W.B., and Iseri, K.T. (1960). *General introduction and hydrologic definitions manual of hydrology. Part 1. General surface-water techniques.* U.S. Geological Survey. Water-Supply Paper 1541-A 29pp. (cited in Cowardin et al. 1979)

LEB website, <http://www.lebmf.gov.au/publications/index.html#progress> accessed 29.5.07

Maher, M., Hawkins, E., and Conrick, D. (2006). *Wetland Indicators Workshop Report.* Queensland Wetlands Programme. Australian Government, Canberra and Queensland Government, Brisbane.

Marshall, J., McGregor, G., Marshall, S., Radcliffe, T., and Lobegeiger, J. (2006b). *Development of conceptual pressure-vector-response models for Queensland's riverine ecosystems.* Natural Resources, Mines & Water, Indooroopilly.

# 12 References

- Marshall, J., Prior, A., Steward, A., and McGregor, G. (2006c). *Freshwater bioregionalisation of Queensland's riverine ecosystems. Development of interim freshwater biogeographic provinces*. Natural Resources, Mines & Water, Indooroopilly.
- Marshall, J.C., Sheldon, F., Thoms, M., and Choy, S. (2006a). The macroinvertebrate fauna of an Australian dryland river: spatial and temporal patterns and environmental relationships. *Marine and Freshwater Research* **57**(1): 61-74.
- McDonald, R.C., Isbell, R.F., Speight, J.G., Walker, J., and Hopkins, M.S. (1990). *Australian Soil and Survey. Field Handbook. Second Edition*. Inkata Press, Melbourne.
- McKenzie, L.J., Campbell, S.J., and Roder, C.A. (2003). *Seagrass-Watch: manual for mapping seagrass resources by community (citizen) volunteers. 2<sup>nd</sup> edition*. DPI, Cairns and CRC Reef, Townsville.
- McNeil, V., and Clarke, R. (2007). State of the Environment Report. Inland Waters – Groundwater Quality. Background report. Natural Resources & Water, Indooroopilly.
- MDBC (2004). *Sustainable Rivers Audit Program*. Murray-Darling Basin Commission, Canberra.
- MEA (2005). *Millennium Ecosystem Assessment. Ecosystems and Human Well-Being: Wetlands and Water – Synthesis*. World Resources Institute, Washington DC.
- Mitsch, W.J., and Gosselink, J.G. (2000). *Wetlands*. 3<sup>rd</sup> edition. John Wiley & Sons, Inc. New York.
- NLWRA (2005). *Monitoring and Evaluation: Queensland Regional Trials, Phase 1 Report*. National Land & Water Resources Audit, Canberra Australia.
- Norris, R.H., Dyer, F., Hairsine, P., Kennard, M., Linke, S., Merrin, L., Read, A., Robinson, W., Ryan, C., Wilkinson, S., and Williams, D. (2007). *Assessment of River and Wetland Health: A framework for comparable assessment of the ecological condition of Australian rivers and wetlands*. Australian Water Resources 2005, National Water Commission.
- NRW (2005). Water quality rapid assessment (GRAM) sampling: AEMF004. Version 1.0. Natural Resources & Water, Brisbane.
- NRW (2006a). Identification and enumeration of aquatic macroinvertebrates to family level: AEMF006. Version 2.0. Natural Resources & Water, Brisbane.
- NRW (2006b). Curation of macroinvertebrates in the laboratory: AEML002. Version 1.0. Natural Resources & Water, Brisbane.
- NRW (2006c). Live-pick macroinvertebrates QRAM: AEMF015. Version 1.0. Natural Resources & Water, Brisbane.
- NRW (2006d). Sampling aquatic macroinvertebrates using a dip net: AEMF005. Version 2.0. Natural Resources & Water, Brisbane.
- NRW (2006e). Aquatic habitat identification: AEMF009. Version 1.0. Natural Resources & Water, Brisbane.
- NRW (2006f). Curation of macroinvertebrates in the field: AEMF010. Version 1.0. Natural Resources & Water, Brisbane.
- NRW (2006g). Environmental measurements (GRAM): AEMF001. Version 1.0. Natural Resources & Water, Brisbane.
- NRW (2006h). Quality assurance of taxonomic identification of aquatic macroinvertebrates to family level (GRAM): AEMQ001. Version 1.0. Natural Resources & Water, Brisbane.
- NRW (2006i). quality assurance of live-picked aquatic macroinvertebrates in the field (GRAM): AEMQ002. Version 5.0. Natural Resources & Water, Brisbane.
- NWI website, <http://www.nwc.gov.au/nwi/index.cfm> accessed 24.1.07
- Schaffelke, B., Mellors, J., and Duke, N.C. (2005). Water quality in the Great Barrier Reef region: responses of mangrove, seagrass and macroalgal communities. *Marine Pollution Bulletin* **51**:279-296.

- Scheltinga, D.M., Counihan, R., Moss, A., Cox, M., and Bennett, J. (2004) *Users' guide to estuarine, coastal and marine indicators for regional NRM monitoring. Report to DEH, MEWG, ICAG. Revised version.* Coastal CRC, Brisbane.
- Scheltinga, D.M., and Moss, A. (in prep.a). *Trialling resource condition indicators for the Queensland coastal zone.* Environmental Protection Agency, Indooroopilly.
- Scheltinga, D.M., and Moss, A. (in prep.b). *Queensland's Stream and Estuary Assessment Program (SEAP). II Estuarine Assessment.* Environmental Protection Agency, Indooroopilly.
- Simpson, J., Norris, R., Barmuta, L., and Blackman, P. (1997). *Australian River Assessment System. National River Health Program Predictive Model Manual.* CRC for Freshwater Ecology, Canberra.
- Simpson, J.C., and Norris, R.H., (2000). Biological assessment of river quality: development of AUSRIVAS models and outputs', in *Assessing the Biological Quality of Fresh Waters. RIVPACS and other Techniques.* (Eds J.F. Wright, D.W. Sutcliffe and M.T. Furse). Proceedings of an International Workshop, 16-18 September 1997, Freshwater Biological Association, United Kingdom.
- Sinclair Knight Merz, *Environmental Water Requirements of Groundwater Dependent Ecosystems* (2001). Environmental Flows Initiative Technical Report Number 2. Commonwealth of Australia, Canberra.
- Smith, M.J., and Storey, A.W. (2000). Project DIBM3: Evaluation/Design and Implementation of Baseline Monitoring. Phase 1, Final Report. Southeast Queensland Regional Water Quality Management Strategy.
- Souter, R., and Mackenzie, R. (2006). *Estuarine, Coastal and Marine Issues and Indicators Workshop. Workshop Report.* Coastal CRC, Brisbane, and Fari Australia.
- Spencer, C., Robertson, A.I., and Curtis, A. (1998). Development and testing of a rapid appraisal wetland condition index in south-eastern Australia. *Journal of Environmental Management* **54**:143-159.
- State of Queensland and Commonwealth of Australia (2003). Reef Water Quality Protection Plan; For catchments adjacent to the Great Barrier Reef World Heritage Area. Queensland Department of Premier and Cabinet, Brisbane
- Sweatman, H. (2007). *Coral reef health indicators and thresholds of concern. Draft report.* Marine and Tropical Sciences Research Facility, Townsville.
- Timms, B.V. (1999). Local runoff, Paroo floods and water extraction impacts on the wetlands of Currawinya National Park. In 'A free-flowing river: The ecology of the Paroo River.' (Ed. R. Kingsford). National Parks and Wildlife Service, NSW.
- Timms, B.V., and Boulton, A.J. (2001). Typology of arid-zone floodplain wetlands of the Paroo river (inland Australia) and the influence of the water regime, turbidity, and salinity on their aquatic invertebrate assemblages. *Archiv für Hydrobiologie* **153**(1):1-27.
- UNESCO (2003). *The 1<sup>st</sup> UN World Water Development Report: Water for People, Water for Life.* UNESCO Publishing/Berghahn Books. [http://www.unesco.org/water/wwap/wwdr1/table\\_contents/index.shtml](http://www.unesco.org/water/wwap/wwdr1/table_contents/index.shtml)
- van Dam, R.A., Camilleri, C., and Finlayson, C.M. (1998). The potential of rapid assessment techniques as early warning indicators of wetland degradation: a review. *Environmental Toxicology and Water Quality* **13**(4):297-312.
- Water Framework Directive website, [http://ec.europa.eu/environment/water/water-framework/info/intro\\_en.htm](http://ec.europa.eu/environment/water/water-framework/info/intro_en.htm), accessed 19.6.07
- Wetland.edu website, <http://www.wetlandsedu.org.au/> accessed 19.6.07
- Wright, J.F., Furse, M.T., and Armitage, P.D. (1993). RIVPACS – a technique for evaluating the biological quality of rivers in the U.K. *European Water Pollution Control*, **3**(4):15-25.

# Appendix 1 Literature Search URLs

The information highlighted throughout this report can be sourced through the links below.

| Reference                                                    | URL                                                                                                                                                                                                                                                                                                   |
|--------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| ANZECC SoE Core Indicators                                   | <a href="http://www.deh.gov.au/soe/publications/indicators/pubs/core-indicators.pdf">http://www.deh.gov.au/soe/publications/indicators/pubs/core-indicators.pdf</a>                                                                                                                                   |
| AquaBAMM                                                     | <a href="http://www.epa.qld.gov.au/register/p02017aa.pdf">http://www.epa.qld.gov.au/register/p02017aa.pdf</a>                                                                                                                                                                                         |
| AusRivAS                                                     | <a href="http://ausriv.as.canberra.edu.au/">http://ausriv.as.canberra.edu.au/</a>                                                                                                                                                                                                                     |
| AusRivAS Physical Assessment                                 | <a href="http://www.environment.gov.au/water/publications/environmental/rivers/nrhp/protocol-1/index.html">http://www.environment.gov.au/water/publications/environmental/rivers/nrhp/protocol-1/index.html</a>                                                                                       |
| Australian Water Resources 2005                              | <a href="http://www.nwc.gov.au/www/html/733-australian-water-resources.asp">http://www.nwc.gov.au/www/html/733-australian-water-resources.asp</a>                                                                                                                                                     |
| AUSWAMP (Davis et al. 1999)                                  | <a href="http://www.science.murdoch.edu.au/centres/aer/publications/WetBioassManual.pdf">http://www.science.murdoch.edu.au/centres/aer/publications/WetBioassManual.pdf</a>                                                                                                                           |
| AUSWAMP (Davis et al. 2001)                                  | <a href="http://www.environment.gov.au/water/publications/environmental/wetlands/pubs/monitor.pdf">http://www.environment.gov.au/water/publications/environmental/wetlands/pubs/monitor.pdf</a>                                                                                                       |
| AUSWAMP (Davis et al. 2006)                                  | <a href="http://www.springerlink.com/content/d1871l3404t5667q/?p=001bd62931a447aeae5b00f96bb57b93&amp;pi=7">http://www.springerlink.com/content/d1871l3404t5667q/?p=001bd62931a447aeae5b00f96bb57b93&amp;pi=7</a>                                                                                     |
| Baldwin et al. (2005)                                        | <a href="http://publication.mdbc.gov.au/product_info.php?products_id=153">http://publication.mdbc.gov.au/product_info.php?products_id=153</a>                                                                                                                                                         |
| Brinson 1993                                                 | <a href="http://el.erdc.usace.army.mil/wetlands/pdfs/wrpde4.pdf">http://el.erdc.usace.army.mil/wetlands/pdfs/wrpde4.pdf</a>                                                                                                                                                                           |
| Butcher (2003)                                               | <a href="http://www.vcmc.vic.gov.au/Web/Docs/SWQMACWetlandFinalReport.pdf">http://www.vcmc.vic.gov.au/Web/Docs/SWQMACWetlandFinalReport.pdf</a>                                                                                                                                                       |
| CBD Secretariat/Ramsar Convention Secretariat (2006)         | <a href="http://www.ramsar.org/lib/lib_rtr01.pdf">http://www.ramsar.org/lib/lib_rtr01.pdf</a>                                                                                                                                                                                                         |
| Clarkson et al. 2004                                         | <a href="http://www.landcareresearch.co.nz/research/biodiversity/landscapesprog/handbook2004.pdf">http://www.landcareresearch.co.nz/research/biodiversity/landscapesprog/handbook2004.pdf</a>                                                                                                         |
| Cowardin et al. 1979                                         | <a href="http://el.erdc.usace.army.mil/emrrp/emris/emrshelp2/cowardin_report.htm">http://el.erdc.usace.army.mil/emrrp/emris/emrshelp2/cowardin_report.htm</a>                                                                                                                                         |
| CRC Freshwater Ecology                                       | <a href="http://www.ewater.canberra.edu.au/domino/html/Site-CRCFE/CRCFE_WebSite.nsf">http://www.ewater.canberra.edu.au/domino/html/Site-CRCFE/CRCFE_WebSite.nsf</a>                                                                                                                                   |
| DIWA                                                         | <a href="http://www.deh.gov.au/water/wetlands/database/directory/index.html">http://www.deh.gov.au/water/wetlands/database/directory/index.html</a>                                                                                                                                                   |
| Duguid 2002                                                  | <a href="http://www.nt.gov.au/nreta/wildlife/nature/aridwetlands.html">http://www.nt.gov.au/nreta/wildlife/nature/aridwetlands.html</a>                                                                                                                                                               |
| East Asian-Australasian shorebird site network               | <a href="http://www.deh.gov.au/biodiversity/migratory/waterbirds/infosrn1.html">http://www.deh.gov.au/biodiversity/migratory/waterbirds/infosrn1.html</a>                                                                                                                                             |
| European Water Framework Directive                           | <a href="http://ec.europa.eu/environment/water/water-framework/index_en.html">http://ec.europa.eu/environment/water/water-framework/index_en.html</a>                                                                                                                                                 |
| Fennessy et al. (2004)                                       | <a href="http://www.epa.gov/owow/wetlands/monitor/RapidMethodReview.pdf">http://www.epa.gov/owow/wetlands/monitor/RapidMethodReview.pdf</a>                                                                                                                                                           |
| Green 1997                                                   | <a href="http://www.dnr.nsw.gov.au/water/pdf/wetclass.pdf">http://www.dnr.nsw.gov.au/water/pdf/wetclass.pdf</a>                                                                                                                                                                                       |
| Great Barrier Reef Water Quality Protection Plan             | <a href="http://www.reefplan.qld.gov.au/">http://www.reefplan.qld.gov.au/</a>                                                                                                                                                                                                                         |
| Health Reefs for Healthy People: Key Indicators              | <a href="http://www.healthyreefs.org/indicators_framework.html">http://www.healthyreefs.org/indicators_framework.html</a>                                                                                                                                                                             |
| Index of Stream Condition (Data Warehouse – 2004 ISC report) | <a href="http://www.vicwaterdata.net/vicwaterdata/data_warehouse_content.aspx?option=5">http://www.vicwaterdata.net/vicwaterdata/data_warehouse_content.aspx?option=5</a>                                                                                                                             |
| Index of Stream Condition (DSE webpage)                      | <a href="http://www.dse.vic.gov.au/DSE/wcmn202.nsf/LinkView/111DC6CA25723E001B5622E2435AAD7CBD0079CA256FEB001C70C6">http://www.dse.vic.gov.au/DSE/wcmn202.nsf/LinkView/111DC6CA25723E001B5622E2435AAD7CBD0079CA256FEB001C70C6</a>                                                                     |
| Index of Wetland Condition (DSE web page)                    | <a href="http://www.dse.vic.gov.au/CA256F310024B628/0/E280AA426603FD63CA2570C8007EE8F5/\$File/IWC+Conceptual+Framework+and+Selection+of+Measures.pdf">http://www.dse.vic.gov.au/CA256F310024B628/0/E280AA426603FD63CA2570C8007EE8F5/\$File/IWC+Conceptual+Framework+and+Selection+of+Measures.pdf</a> |
| Indicator methods                                            | <a href="http://www.nrm.gov.au/publications/factsheets/me-indicators/index.html">http://www.nrm.gov.au/publications/factsheets/me-indicators/index.html</a> or <a href="http://www.nrm.gov.au/me/index.html">http://www.nrm.gov.au/me/index.html</a>                                                  |
| Jaensch 1999                                                 | <a href="http://www.epa.qld.gov.au/wetlandinfo/site/factsfigures/SummaryInformation/WetlandHabitats.html">http://www.epa.qld.gov.au/wetlandinfo/site/factsfigures/SummaryInformation/WetlandHabitats.html</a>                                                                                         |

| Reference                                                                            | URL                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|--------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Johnson and Gerbeaux 2004                                                            | <a href="http://www.doc.govt.nz/upload/documents/science-and-technical/Wetlands BWa.pdf">http://www.doc.govt.nz/upload/documents/science-and-technical/Wetlands BWa.pdf</a>                                                                                                                                                                                                                                                                                                                                                                                                 |
| LEB website                                                                          | <a href="http://www.lebmf.gov.au/">http://www.lebmf.gov.au/</a>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| Matters for Target                                                                   | <a href="http://www.nlwra.gov.au/">http://www.nlwra.gov.au/</a>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| Narran Lakes project                                                                 | <a href="http://hds.canberra.edu.au/narran/index.html">http://hds.canberra.edu.au/narran/index.html</a>                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| National NRM M&E Framework                                                           | <a href="http://www.nrm.gov.au/publications/frameworks/me-framework.html">http://www.nrm.gov.au/publications/frameworks/me-framework.html</a>                                                                                                                                                                                                                                                                                                                                                                                                                               |
| National Water Initiative                                                            | <a href="http://www.nwc.gov.au/nwi/index.cfm">http://www.nwc.gov.au/nwi/index.cfm</a>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| NLWRA                                                                                | <a href="http://www.nlwra.gov.au/">http://www.nlwra.gov.au/</a>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| NLWRA Monitoring and Evaluation Trials Queensland Region Phase 1 Report (NLWRA 2005) | <a href="http://archive.nlwra.gov.au/Publications_and_Tools/Project_Reports/Monitoring_and_Evaluation_Trials_New_South_Wales_Region_Phase_2_Report/indexdl_5355.aspx">http://archive.nlwra.gov.au/Publications_and_Tools/Project_Reports/Monitoring_and_Evaluation_Trials_New_South_Wales_Region_Phase_2_Report/indexdl_5355.aspx</a>                                                                                                                                                                                                                                       |
| NRHP                                                                                 | <a href="http://www.environment.gov.au/water/index.html">http://www.environment.gov.au/water/index.html</a>                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| Qld Freshwater EHMP                                                                  | <a href="http://www.ehmp.org/freshwater_monitoring.html">http://www.ehmp.org/freshwater_monitoring.html</a>                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| Ramsar classification                                                                | <a href="http://www.ramsar.org/ris/key_ris.htm#type">http://www.ramsar.org/ris/key_ris.htm#type</a>                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| Rapid Appraisal of Riparian Condition (RARC)                                         | <a href="http://www.lwa.gov.au/downloads/publications_pdf/PR050994.pdf">http://www.lwa.gov.au/downloads/publications_pdf/PR050994.pdf</a>                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| Regional Ecosystems (Qld EPA)                                                        | <a href="http://www.epa.qld.gov.au/nature_conservation/biodiversity/regional_ecosystems/">http://www.epa.qld.gov.au/nature_conservation/biodiversity/regional_ecosystems/</a>                                                                                                                                                                                                                                                                                                                                                                                               |
| Riverstyles®                                                                         | <a href="http://www.riverstyles.com/">http://www.riverstyles.com/</a>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| Semeniuk 1996                                                                        | <a href="http://portal.environment.wa.gov.au/portal/page?_pageid=55,5625145&amp;_dad=portal&amp;_schema=PORTAL">http://portal.environment.wa.gov.au/portal/page?_pageid=55,5625145&amp;_dad=portal&amp;_schema=PORTAL</a>                                                                                                                                                                                                                                                                                                                                                   |
| SIGNAL Index (Chessman 2003)                                                         | <a href="http://www.environment.gov.au/water/publications/environmental/rivers/nrhp/pubs/signal.pdf">http://www.environment.gov.au/water/publications/environmental/rivers/nrhp/pubs/signal.pdf</a>                                                                                                                                                                                                                                                                                                                                                                         |
| Spencer et al 1998                                                                   | <a href="http://www.sciencedirect.com/science?_ob=ArticleURL&amp;_udi=B6WJ7-45SJDWY-5&amp;_user=2627777&amp;_rdoc=1&amp;_fmt=&amp;_orig=search&amp;_sort=d&amp;view=c&amp;acct=C000058262&amp;_version=1&amp;_urlVersion=0&amp;_userid=2627777&amp;md5=fa2b720806868b5e42efd4c31be7931b">http://www.sciencedirect.com/science?_ob=ArticleURL&amp;_udi=B6WJ7-45SJDWY-5&amp;_user=2627777&amp;_rdoc=1&amp;_fmt=&amp;_orig=search&amp;_sort=d&amp;view=c&amp;acct=C000058262&amp;_version=1&amp;_urlVersion=0&amp;_userid=2627777&amp;md5=fa2b720806868b5e42efd4c31be7931b</a> |
| State of the Rivers (Qld)                                                            | <a href="http://www.nrw.qld.gov.au/science/state_of_rivers/index.html">http://www.nrw.qld.gov.au/science/state_of_rivers/index.html</a>                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Sustainable Rivers Audit (SRA)                                                       | <a href="http://www.mdbc.gov.au/SRA">http://www.mdbc.gov.au/SRA</a>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| SWAMPS (Chessman et al. 2002)                                                        | <a href="http://www.publish.csiro.au/nid/126/paper/MF00079.htm">http://www.publish.csiro.au/nid/126/paper/MF00079.htm</a>                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| Tasmanian CFEV                                                                       | <a href="http://www.dpiw.tas.gov.au/inter.nsf/WebPages/CGRM-7JHVSJ?open">http://www.dpiw.tas.gov.au/inter.nsf/WebPages/CGRM-7JHVSJ?open</a>                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| Tropical Rapid Appraisal of Riparian Condition (TRARC)                               | <a href="http://www.lwa.gov.au/downloads/publications_pdf/PR061169.pdf">http://www.lwa.gov.au/downloads/publications_pdf/PR061169.pdf</a>                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| USEPA: Methods for Evaluating Wetland Condition                                      | <a href="http://www.epa.gov/waterscience/criteria/wetlands">http://www.epa.gov/waterscience/criteria/wetlands</a>                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| Van Dam et al. (1998)                                                                | <a href="http://www3.interscience.wiley.com/cgi-bin/abstract/10008660/ABSTRACT">http://www3.interscience.wiley.com/cgi-bin/abstract/10008660/ABSTRACT</a>                                                                                                                                                                                                                                                                                                                                                                                                                   |
| Waterwatch                                                                           | <a href="http://www.waterwatch.org.au/index.html">http://www.waterwatch.org.au/index.html</a>                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| Waterwatch technical manual                                                          | <a href="http://www.waterwatch.org.au/publications/index.html">http://www.waterwatch.org.au/publications/index.html</a>                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| WetlandCare Australia                                                                | <a href="http://www.wetlandcare.com.au/">http://www.wetlandcare.com.au/</a>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |

# Appendix 2 Wetland classification systems

## 1. Ramsar Classification System for Wetland Type

## 2. A Directory of Important Wetlands in Australia

(Agreed by NRMMC Taskforce on Wetlands and Waterbirds June 2004)

### 1. Ramsar Classification System

#### Marine/Coastal Wetlands

- A Permanent shallow marine waters** in most cases less than six metres deep at low tide; includes sea bays and straits.
- B Marine subtidal aquatic beds**; includes kelp beds, sea-grass beds, tropical marine meadows.
- C Coral reefs.**
- D Rocky marine shores**; includes rocky offshore islands, sea cliffs.
- E Sand, shingle or pebble shores**; includes sand bars, spits and sandy islets; includes dune systems and humid dune slacks.
- F Estuarine waters**; permanent water of estuaries and estuarine systems of deltas.
- G Intertidal mud, sand or salt flats.**
- H Intertidal marshes**; includes salt marshes, salt meadows, saltings, raised salt marshes; includes tidal brackish and freshwater marshes.
- I Intertidal forested wetlands**; includes mangrove swamps, nipah swamps and tidal freshwater swamp forests.
- J Coastal brackish/saline lagoons**; brackish to saline lagoons with at least one relatively narrow connection to the sea.
- K Coastal freshwater lagoons**; includes freshwater delta lagoons.
- Zk(a) Karst and other subterranean hydrological systems**, marine/coastal

#### Inland Wetlands

- L Permanent inland deltas.**
- M Permanent rivers/streams/creeks**; includes waterfalls.
- N Seasonal/intermittent/irregular rivers/streams/creeks.**
- O Permanent freshwater lakes** (over 8 ha); includes large oxbow lakes.
- P Seasonal/intermittent freshwater lakes** (over 8 ha); includes floodplain lakes.
- Q Permanent saline/brackish/alkaline lakes.**
- R Seasonal/intermittent saline/brackish/alkaline lakes and flats.**
- Sp Permanent saline/brackish/alkaline marshes/pools.**
- Ss Seasonal/intermittent saline/brackish/alkaline marshes/pools.**
- Tp Permanent freshwater marshes/pools**; ponds (below 8 ha), marshes and swamps on inorganic soils; with emergent vegetation water-logged for at least most of the growing season.
- Ts Seasonal/intermittent freshwater marshes/pools on inorganic soils**; includes sloughs, potholes, seasonally flooded meadows, sedge marshes.
- U Non-forested peatlands**; includes shrub or open bogs, swamps, fens.
- Va Alpine wetlands**; includes alpine meadows, temporary waters from snowmelt.
- Vt Tundra wetlands**; includes tundra pools, temporary waters from snowmelt.

**W Shrub-dominated wetlands;** shrub swamps, shrub-dominated freshwater marshes, shrub carr, alder thicket on inorganic soils.

**Xf Freshwater, tree-dominated wetlands;** includes freshwater swamp forests, seasonally flooded forests, wooded swamps on inorganic soils.

**Xp Forested peatlands;** peat swamp forests.

**Y Freshwater springs;** oases.

**Zg Geothermal wetlands**

**Zk(b) – Karst and other subterranean hydrological systems, inland**

Note: "floodplain" is a broad term used to refer to one or more wetland types, which may include examples from the R, Ss, Ts, W, Xf, Xp, or other wetland types. Some examples of floodplain wetlands are seasonally inundated grassland (including natural wet meadows), shrublands, woodlands and forests. Floodplain wetlands are not listed as a specific wetland type herein.

Human-made wetlands

**1 Aquaculture** (e.g., fish/shrimp) **ponds**

**2 Ponds;** includes farm ponds, stock ponds, small tanks; (generally below 8 ha).

**3 Irrigated land;** includes irrigation channels and rice fields.

**4 Seasonally flooded agricultural land** (including intensively managed or grazed wet meadow or pasture).

**5** Salt exploitation sites; salt pans, salines, etc.

**6** Water storage areas; reservoirs/barrages/dams/impoundments (generally over 8 ha).

**7** Excavations; gravel/brick/clay pits; borrow pits, mining pools.

**8** Wastewater treatment areas; sewage farms, settling ponds, oxidation basins, etc.

**9** Canals and drainage channels, ditches.

**Zk(c) – Karst and other subterranean hydrological systems, human-made**

## Appendix 2 Wetland classification systems

| Marine/Coastal Wetlands         |                  |                           |       |
|---------------------------------|------------------|---------------------------|-------|
| Saline Water                    | Permanent        | < 6m deep                 | A     |
|                                 |                  | Underwater vegetation     | B     |
|                                 |                  | Coral Reefs               | C     |
|                                 | Shores           | Rocky                     | D     |
|                                 |                  | Sand, shingle or pebble   | E     |
| Saline or brackish water        | Intertidal       | Flats (mud, sand or salt) | G     |
|                                 |                  | Marshes                   | II    |
|                                 |                  | Forested                  | I     |
|                                 | Lagoons          |                           | J     |
|                                 | Estuarine waters |                           | F     |
| Saline, brackish or fresh water | Subterranean     |                           | Zk(a) |
| Fresh water                     | Lagoons          |                           | K     |

| Marine/Coastal Wetlands                   |                                    |                                     |                         |       |
|-------------------------------------------|------------------------------------|-------------------------------------|-------------------------|-------|
| Fresh water                               | Flowing water                      | Permanent                           | Rivers, streams, creeks | M     |
|                                           |                                    |                                     | Deltas                  | L     |
|                                           |                                    |                                     | Springs, oases          | Y     |
|                                           |                                    | Seasonal/intermittent               | Rivers, streams, creeks | N     |
|                                           | Lakes and pools                    | Permanent                           | >8ha                    | O     |
|                                           |                                    |                                     | <8ha                    | Tp    |
|                                           |                                    | Seasonal/intermittent               | >8ha                    | P     |
|                                           |                                    |                                     | <8ha                    | Ts    |
|                                           | Marshes on inorganic soils         | Permanent                           | Herb-dominated          | Tp    |
|                                           |                                    | Permanent/Seasonal/<br>intermittent | Shrub-dominated         | W     |
|                                           |                                    |                                     | Tree-dominated          | Xf    |
|                                           |                                    | Seasonal/intermittent               | Herb-dominated          | Ts    |
|                                           | Marshes on peat soils              | Permanent                           | Non-forested            | U     |
|                                           |                                    |                                     | Forested                | Xp    |
|                                           | Marshes on inorganic or peat soils | High altitude (alpine)              |                         | Va    |
|                                           |                                    | Tundra                              |                         | Vt    |
| Saline, brackish or alkaline water        | Lakes                              | Permanent                           |                         | Q     |
|                                           |                                    | Seasonal/intermittent               |                         | R     |
|                                           | Marshes and pools                  | Permanent                           |                         | Sp    |
|                                           |                                    | Seasonal/intermittent               |                         | Ss    |
| Fresh, saline, brackish or alkaline water | Geothermal                         |                                     |                         | Zg    |
|                                           | Subterranean                       |                                     |                         | Zk(b) |

# Appendix 2 Wetland classification systems

## 2. Directory of Important Wetlands of Australia (DIWA) classification

### A – Marine and Coastal Zone wetlands

- Marine waters; permanent shallow waters less than six metres deep at low tide; includes sea bays, straits
- Subtidal aquatic beds; includes kelp beds, seagrasses, tropical marine meadows
- Coral reefs
- Rocky marine shores; includes rocky offshore islands, sea cliffs, intertidal rock platforms
- Sand, shingle or pebble beaches; includes sand bars, spits, sandy islets
- Estuarine waters; permanent waters of estuaries and estuarine systems of deltas
- Tidal mud, sand or salt flats; intertidal or supratidal
- Tidal marshes; includes intertidal or supratidal saltmarshes, salt meadows, saltings, brackish and freshwater marshes
- Tidal forested wetlands; includes intertidal or supratidal mangrove swamps, nipa/palm swamps, freshwater swamp forests
- Brackish to saline lagoons and marshes with one or more relatively narrow connections with the sea; includes tidal inlets periodically blocked by sand
- Freshwater lagoons and marshes in the coastal zone
- Non-tidal freshwater forested wetlands, permanently or temporarily flooded
- Karst or subterranean wetlands with a connection to the marine environment, includes anchialine systems

### B – Inland wetlands

- Permanent rivers and streams; includes waterfalls, permanent waterholes in river reaches
- Seasonal and irregular rivers and streams; includes minor anabranches, braided channel complexes
- Inland deltas (permanent and temporary)
- Riverine floodplains; includes temporarily flooded river flats, river basins, grassland, savanna and palm savanna
- Permanent freshwater lakes (> 8 ha); includes large oxbow lakes
- Seasonal/intermittent freshwater lakes (> 8 ha), floodplain lakes, billabongs, claypans
- Permanent saline/brackish lakes
- Seasonal/intermittent saline lakes
- Permanent freshwater ponds (< 8 ha), marshes and swamps on inorganic soils; with emergent vegetation waterlogged for at least most of the growing season
- Seasonal/intermittent freshwater ponds and marshes on inorganic soils; includes claypan complexes, seasonally flooded canegrass/grass swamps, sedge, rush and reed swamps
- Permanent saline/brackish marshes
- Seasonal saline marshes
- Freshwater shrub swamps; shrub-dominated marsh on inorganic soils, includes lignum, ti-tree swamps
- Freshwater swamp forest, seasonally flooded forest, wooded swamps, on inorganic soils; includes river red gum forest, paperbark, coolibah and belah/sheoak swamps
- Peatlands; forest, shrub or open bogs
- Alpine wetlands; includes alpine meadows and pools, temporary waters from snow melt
- Freshwater springs, oases and rock pools; includes gnamma holes, mineralised mound and artesian springs
- Geothermal wetlands
- Inland, subterranean karst wetlands

### C – Human-made wetlands

- Water storage areas; reservoirs, barrages, hydro-electric dams, impoundments (generally > 8 ha)
- Ponds, including farm ponds, stock ponds, small tanks (generally < 8 ha)
- Aquaculture ponds; fish ponds, shrimp ponds
- Salt exploitation; salt pans, salines
- Excavations; gravel pits, borrow pits, mining pools
- Wastewater treatment; sewage farms, settling ponds, oxidation basins
- Irrigated land and irrigation channels, canals or ditches; includes rice fields
- Seasonally flooded arable land, farm land
- Canals, stormwater drains
- Wetlands constructed for biodiversity benefit; includes for habitat creation, and water quality improvement or maintenance

# Attachment A

## Wetland Indicators Workshop Report

September 2006

Mary Maher, Mary Maher & Associates

Emma Hawkins, Lloyd Consulting

Diane Conrick, Department of Natural Resources & Water

---

### Acknowledgements

This document is the proceedings and findings of a workshop to scope and agree on the key indicators for monitoring wetlands extent and condition in Queensland. The workshop was designed by the workshop facilitator, Mary Maher, and Project Leader, Diane Conrick, in consultation with Mike Ronan of the Environmental Protection Agency and Bruce Gray of the Department of the Environment, Heritage, Water and Arts. The participants at the workshop are acknowledged and thanked for their attendance at the workshop. This document records your contributions.

The Environmental Protection Agency funded Kate Moore of the University of Queensland to illustrate the conceptual models developed by the workshop participants (Figures 4, 5, 6, 7 and Appendices F and G). The symbols used are courtesy of the Integration and Application Network ([ian.umces.edu/symbols/](http://ian.umces.edu/symbols/)), University of Maryland Center for Environmental Science.

---

# Contents

|                                                                               |            |
|-------------------------------------------------------------------------------|------------|
| <b>1 Executive Summary.....</b>                                               | <b>167</b> |
| <b>2 Introduction.....</b>                                                    | <b>168</b> |
| 2.1 Background information.....                                               | 168        |
| 2.2 The Wetland Indicators project.....                                       | 168        |
| 2.3 The workshop report .....                                                 | 168        |
| <b>3 Background to the Experts' Workshop.....</b>                             | <b>169</b> |
| <b>4 Building the Indicator Framework.....</b>                                | <b>170</b> |
| 4.1 Considerations for defining indicators .....                              | 170        |
| 4.1.1 Classification into wetlands types and sub-types.....                   | 170        |
| 4.1.2 Indicators 'fit for purpose' .....                                      | 170        |
| 4.1.3 Spatial scale .....                                                     | 171        |
| 4.1.4 Temporal scale.....                                                     | 171        |
| 4.1.5 Practicality: Skill level and cost requirements .....                   | 171        |
| 4.2 Wetland classification and building the indicators framework .....        | 172        |
| 4.3 Generic and specific indicators .....                                     | 172        |
| <b>5 The Indicator Framework .....</b>                                        | <b>173</b> |
| 5.1 Wetland indicator identification framework.....                           | 173        |
| 5.2 Wetland indicator considerations – a worked example.....                  | 174        |
| <b>6 Lacustrine Wetlands .....</b>                                            | <b>175</b> |
| 6.1 Lacustrine conceptual model .....                                         | 175        |
| 6.2 Lacustrine sub-type conceptual models.....                                | 179        |
| 6.2.1 Coastal dune lakes eg. Blue Lake, Stradbroke Island (window lake) ..... | 179        |
| 6.2.2 Terminal depression lakes .....                                         | 179        |
| 6.2.3 Depression lakes (inland, non-arid) .....                               | 180        |
| 6.2.4 Artificial lakese.g. Water supply dam .....                             | 181        |
| 6.2.5 Arid-zone saltwater river-fed lakes .....                               | 181        |
| 6.2.6 Inland salt lakes.....                                                  | 182        |
| <b>7 Palustrine Wetlands.....</b>                                             | <b>182</b> |
| 7.1 Palustrine conceptual models .....                                        | 182        |
| 7.2 Palustrine sub-type conceptual models.....                                | 186        |
| 7.2.1 Coastal forest swamps e.g. Melaleuca, Casuarina .....                   | 186        |
| 7.2.2 Coastal grass-sedge swampse.g. Bulkuru sedge.....                       | 187        |
| 7.2.4 Artificial (bore drains) .....                                          | 188        |
| 7.2.5 Natural groundwater springs.....                                        | 188        |
| 7.2.6 Herbs and forbs .....                                                   | 189        |
| 7.2.7 Freshwater meadows .....                                                | 189        |

# Attachment A

## Wetland Indicators Workshop Report

|                                                                            |            |
|----------------------------------------------------------------------------|------------|
| <b>8 Groundwater .....</b>                                                 | <b>190</b> |
| <b>9 Other Key Discussion Points .....</b>                                 | <b>191</b> |
| 9.1 Characterising wetlands .....                                          | 191        |
| 9.1.1 Reference condition .....                                            | 191        |
| 9.1.2 Value judgements – setting environmental values for management ..... | 191        |
| 9.2 Risk management approaches .....                                       | 191        |
| 9.3 Remote methods or ground testing – when and why? .....                 | 191        |
| 9.4 Extent of the wetlands .....                                           | 191        |
| 9.5 Users’ needs and capabilities .....                                    | 192        |
| <b>10 Summary .....</b>                                                    | <b>192</b> |
| <b>11 Way Forward .....</b>                                                | <b>193</b> |

### Attachment List of Figures

|                                                                                                   |     |
|---------------------------------------------------------------------------------------------------|-----|
| Figure 1. Indicator specification. ....                                                           | 172 |
| Figure 2. Indicator framework. ....                                                               | 173 |
| Figure 3. Worked example of applying the matrix for a set indicator over a range of purposes..... | 174 |
| Figure 4. Lacustrine wetland (wet phase) conceptual model.....                                    | 177 |
| Figure 5. Lacustrine wetland (dry phase) conceptual model.....                                    | 178 |
| Figure 6. Palustrine wetland (wet phase) conceptual model.....                                    | 184 |
| Figure 7. Palustrine wetland (dry phase) conceptual model .....                                   | 185 |

### Attachment List of Appendices

|                                                       |     |
|-------------------------------------------------------|-----|
| Appendix A: Workshop Program – June 8 & 9, 2006 ..... | 194 |
| Appendix B: Participant List.....                     | 195 |
| Appendix C: Presentations .....                       | 197 |
| Appendix D: Workshop Groups .....                     | 212 |
| Appendix E: Palustrine/Lacustrine Definitions.....    | 214 |
| Appendix F: Lacustrine Conceptual Models .....        | 216 |
| Appendix F: Palustrine Conceptual Models .....        | 222 |

# 1 Executive Summary

The Queensland Wetlands Programme is a joint initiative of the Australian and Queensland Governments to support projects and programs that will result in long-term benefits to the sustainable use, management, conservation and protection of Queensland wetlands. The 'Scoping Study for Monitoring of Wetlands Extent and Condition' project was developed to support the outcomes of two other Programme projects: The development of a Wetlands Inventory Database, and the baseline resource condition monitoring program for the Queensland Wetlands Programme Monitoring, Evaluation and Reporting Strategy (MER Strategy).

This report presents the results of the one and a half day experts' workshop held in Brisbane 8-9 June 2006. Participants included representatives from a wide range of government, academia, consulting and NRM groups from Queensland and elsewhere in Australia.

The aim of the experts' workshop was to scope and agree on the key indicators for monitoring wetlands extent and condition in Queensland. The workshop participants identified five key areas requiring consideration when identifying wetland indicators (see section 4). The five areas of consideration are:

- Classification wetlands types and sub-types.
- Purpose baseline condition and trend, cause and effect, or management responses.
- Spatial scale individual, regional, state, national or international.
- Time scale short, medium, or long term.
- Practicality skill level required, and cost.

The workshop discussion resolved that the framework of indicators would include a generic suite of indicators applicable to all wetlands, and a set of indicators tailored for subtypes of wetlands within defined climatic regions (section 4).

The report presents the workshop results which were:

- a framework for indicator identification (section 5);
- conceptual models developed for two of the three wetland types: lacustrine, and palustrine (sections 6 and 7 respectively);

- conceptual models for subtypes of lacustrine and palustrine types (sections 6.2 and 7.2 respectively); and
- accompanying descriptors for these types and sub-types which form candidate indicators depending on the framework of determining factors for the selection process.

The process of developing indicators for lacustrine, palustrine and groundwater wetlands involved constructing a generic conceptual model of a wetland, and identifying a list of hypothetical indicators (see sections 6, 7 and 8). Following this, conceptual models were constructed for subtypes of wetlands, with the key features, pressures and a list of initial indicators for these sub-types discussed

The workshop produced a number of insights around the development of an indicator framework for wetland extent and condition:

- Wetland indicators must have a defined purpose. The indicator and assessment method must be tailored to meet this purpose.
- The level of information required to be produced by the indicator must be defined in terms of temporal and spatial scale.
- The appropriateness of the level of skill required and cost-effectiveness of the assessment methods are critical determining factors, in developing an indicator framework.
- There is a risk in using descriptive elements as indicators. In some instances, however, descriptors may be able to function as indicators.
- An indicator framework will include a matrix of generic and specific indicators.
- A level of background knowledge is required, in order to accurately assess the condition and extent of a wetland, with regard to the individual wetland cycle, or regional climatic system.
- Conceptual models will be developed.
- There is a possibility of taking a risk based approach.
- Types of indicators could align with the three elements of pressure, vector, and response.

Through the workshop process, conceptual models were constructed for the following lacustrine wetland sub-types (see section 6):

- coastal dune lakes;
- terminal depression lakes;

# Attachment A

## Wetland Indicators Workshop Report

- depression lakes (inland, non-arid);
- artificial lakes;
- arid-zone, saltwater, river-fed lakes; and
- inland salt lakes.

Conceptual models were also constructed for the following palustrine wetland sub-types (see section 7):

- coastal forest swamps;
- coastal sedge swamps;
- inland arid-zone swamps;
- artificial (bore drains);
- natural groundwater springs;
- herbs and forbs; and
- freshwater meadows.

Other key discussion points (section 9) looked at the challenges around characterising wetlands, wetland indicators for risk management approaches, the preference for remote methods or ground-testing, problems of defining the extent of wetlands, and identifying and prioritising users' needs and capabilities.

To progress this scoping work further, participants agreed there is a need for a commitment from the State and Federal Governments in terms of financial and human resource contributions, and that regional involvement would be an integral aspect of this process. It was also suggested that the conceptual models for the wetland types and sub-types would be further developed with the assistance of specialists before undergoing a peer review process.

It was agreed that participants would be sent the key findings/outcomes of the workshop, and be given the opportunity to comment on the draft report. In order to foster ongoing information sharing and discussion on the topics raised in the workshop, an email network is to be established. A desired outcome of this information sharing is a complete database of potential assessment methods in use throughout Australia.

It was noted that workshop participants may be interested in further involvement through small group workshops based around key themes.

## 2 Introduction

### 2.1 Background information

The Queensland Wetlands Programme is a joint initiative of the Australian and Queensland Governments to support projects and programs that will result in long-term benefits to the sustainable use, management, conservation and protection of Queensland wetlands. It is funded through two sub-programs: the Great Barrier Reef Coastal Wetlands Protection Program, and the Natural Heritage Trust Wetlands Programme.

The Queensland Environmental Protection Agency (EPA) is the lead State agency with support from the Departments of Natural Resources and Water (NRW), Primary Industries and Fisheries (DPI&F), and Local Government, Planning, Sport and Recreation (DLGPS&R). The Australian Government is represented by the Department of Environment and Heritage (DEH) and the Great Barrier Reef Marine Park Authority (GBRMPA).

### 2.2 The Wetland Indicators project

The 'Scoping Study for Monitoring of Wetlands Extent and Condition' project was developed to support the outcomes of two other Programme projects: The development of a Wetlands Inventory Database, and the baseline resource condition monitoring program for the Queensland Wetlands Programme Monitoring, Evaluation and Reporting Strategy (MER Strategy).

This project aims to provide an overall strategy to develop appropriate indicators for assessing Queensland wetland extent and condition through a process of review and consultation. The project has involved an extensive review of existing information, research and practices, and an experts' workshop. The workshop was aimed at providing the platform for ongoing discussion and information sharing between wetland experts across Australia. The final task of the project is to inform the national review of the existing 'Matters for Target' wetland indicators.

### 2.3 The workshop report

This report is structured differently to the workshop agenda and outcomes, in that the framework was delivered in the final sessions of the workshop after

the development of the relevant conceptual models and much discussion around the development of indicators. It is presented first in this report as it was seen to underpin the validity of the process of developing conceptual models and selecting indicators.

### 3 Background to the Experts' Workshop

This report presents the results of the one and a half day experts' workshop held in Brisbane 8-9 June 2006. The workshop agenda is included in Appendix A. Participants included representatives from a wide range of government, academia, consulting and NRM groups from Queensland and elsewhere in Australia (see Appendix B).

The aim of the experts' workshop was to scope and agree on the key indicators for monitoring wetlands extent and condition in Queensland. A workshop trigger paper was circulated prior to the workshop to orient participants.

The workshop was designed to focus on three wetland types: lacustrine, palustrine and groundwater. The workshop program consisted of a series of brief presentations by wetland specialists from across Australia. The speakers presented material ranging from general information on techniques for defining indicators to more specific information about the Queensland Wetlands Programme (see Appendix C). The presentation sessions were to provide important information, develop interest, and orient participants to the task of scoping indicators for wetlands extent and condition for lacustrine, palustrine and groundwater wetlands.

A second feature of the structure was the use of model-building exercises where participants constructed and tested 'conceptual models' of wetland processes and mapped the impact of the different drivers and pressures for each. The participant groups for lacustrine and palustrine wetland sub-types are included in Appendix D. The insights and results from these exercises highlighted the challenges of wetland indicator identification, while producing some potential indicators. Definitions from the literature for Lacustrine and Palustrine wetlands are in Appendix E. As an aid to

understanding wetland type and selecting indicators, the conceptual models developed in the workshop were illustrated (Figures 4, 5, 6, 7, and Appendices F and G).

Wetlands are very complex and the task put to the workshop participants to identify indicators was a difficult one. There are many different types of wetlands, and many different processes and pressures acting in each wetland. Given these difficulties, it is a credit to the participants that there were clear achievements from the workshop which will take forward the understanding of wetland function and provide a consistent framework with which investigators can work.

This report presents the workshop results, which were;

- A framework for indicator identification (Section 5).
- Conceptual models developed for two of the three wetland types: lacustrine and palustrine (sections 6 and 7 respectively).
- Conceptual models for subtypes of lacustrine and palustrine types (sections 6.2 and 7.2, Appendices F and G, respectively).
- Accompanying descriptors for these wetland types and sub-types which form candidate indicators depending on the framework of considerations, or determining factors, for the selection process.

# Attachment A

## Wetland Indicators Workshop Report

### 4 Building the Indicator Framework

#### 4.1 Considerations for defining indicators

The workshop included a presentation outlining criteria for a list of desired properties. The following list of potential properties or attributes of wetland indicators was provided (see Appendix C5):

- Suitable for use within multiple Natural Resource Management processes.
- Capacity to be grouped into a suite of indicators for use at a range of spatial scales from local to national and international.
- Cost-effective.
- Efficient in terms of time requirements.
- SMART: smart, measurable, accurate, relevant, and timely.
- Capacity to be tested using existing technical capabilities.

The group exercise of constructing a conceptual model of a lacustrine wetland produced a number of key questions and challenges in defining wetlands indicators. Subsequent sessions on palustrine and groundwater wetlands saw a refinement and reinforcement of the importance of these considerations as determining factors for identification of indicators.

These considerations were grouped into five areas:

- Classification: wetlands types and sub-types.
- Purpose: baseline condition and extent, cause and effect, or management responses.
- Spatial Scale: individual, regional, state, national or international.
- Time Scale: short, medium, or long term.
- Practicality: skill level required (minimum, intermediate, or advanced), and economic feasibility (low, medium, or high cost).

#### 4.1.1 Classification into wetlands types and sub-types

Wetlands are inherently dynamic systems, undergoing cycles of wet and dry phases, and a suite of processes, and changes. As a result of this flux, the classification of a wetland into lacustrine, palustrine and groundwater types is somewhat superficial, and inaccurate. A more accurate description would depict lacustrine, palustrine and groundwater wetlands as positions along a wetland function spectrum. The grouping of wetlands into these classifications is of less relevance within Australia, as there exists much more of a continuance between wetland types than in other parts of the world (namely North America and Europe).

One example of this continuum of Australian wetlands is the lacustrine wetland, which, after an extended dry phase, exhibits palustrine characteristics. Further to this, many lacustrine and palustrine wetlands are closely linked and, in some cases, dependant on groundwater wetlands.

The workshop discussion concluded that while this classification of wetland types (lacustrine, palustrine and groundwater) may not reflect current knowledge and research on wetland types, it is useful for grouping wetlands into broad types for the purposes of this exercise.

Regional climate and weather systems and the local geological features have the potential to significantly impact a wetland, to the point of creating wetlands featuring a unique system of processes, functions and cycles. This is of most significance in the process of interpreting information from indicators. The risk of grouping wetlands into types and sub-types is that the interpretation of this information may be inaccurate if background information on the individual wetland is not known. The requirement for wetland-specific information is further discussed in section 9.5.

#### 4.1.2 Indicators ‘fit for purpose’

Potential pathways, or uses, of the indicator framework were outlined in a workshop presentation as (see Appendix C9):

- The potential to be linked to management actions.
- The potential to show the condition and the key driver, pressure or processes causing change.

Further to this, it was noted that if process drivers are used as indicators, the linkages between processes and features or changes must be understood.

- The potential for indicators to be grouped into components and services.

A key finding from the workshop discussion of indicator selection was the need for clarity of the purpose, or end user, of an indicator in order to ensure an appropriate indicator and assessment method is defined. It was noted that indicators could deliver information for a number of purposes including: an indicator of baseline condition and extent, a description of drivers and associated changes within the wetland, and assessment of condition, pressures and responses to inform decision making for management responses. An example of this can be seen in section 4.3.

It was noted that the primary focus and driver of the Queensland Wetlands Programme is to monitor the extent and condition of wetlands in order to inform management action targets and resource condition/assessment targets. The indicators developed for this process must therefore be refined to meet this purpose. Further to this, it was acknowledged that the indicator framework and learnings from this process may go beyond the Programme.

Additional potential purposes for indicators included assessing condition and disturbance, prioritising investment, satisfying legal requirements/compliance, and to gain an improved understanding of wetland processes.

### 4.1.3 Spatial scale

In order to accurately define wetland indicators, the spatial scale for assessment should be defined. There is a need to clarify whether the indicator would be used generically for a suite of wetlands at the regional, state, national or international level, or if the indicators are being defined for individual wetlands, or specific climatic regions. The indicator and the assessment method may vary according to the chosen spatial scale.

### 4.1.4 Temporal scale

Timing of monitoring is one major consideration. Another is the time scale and its impact on indicator

selection. There is a need to have a comprehensive understanding of the cyclic changes of the wetlands over time. One suggestion was that ecological indicators be limited to those elements that are considered permanent. Indicators may be selected to work best for different time periods – short, medium and long term, or because they are not greatly impacted by time considerations. Questions of desired temporal scale will affect the indicators selected and monitoring method employed.

The time scale being addressed is a crucial element in assessing wetland condition and extent. It was noted that the temporal scale of the information required will affect the assessment method used, and that there is a need to have a comprehensive understanding of the cyclic changes of the wetland being assessed over time. It was suggested that ecological indicators be limited to those elements that are considered permanent e.g. vegetation, geomorphology.

### 4.1.5 Practicality: Skill level and cost requirements

The workshop discussion resolved that indicators and monitoring methods should be developed for a range of potential monitoring bodies:

- landholders/managers and community members/groups;
- local governments;
- regional Natural Resource Management (NRM) bodies;
- state governments;
- Commonwealth government; and
- university research programs.

At the community level, basic testing, photographic assessment and shadow monitoring were suggested methods. At the higher levels, it was noted that operators would need to have more advanced skills and an understanding of the link between the patterns and processes, rather than focusing solely on patterns.

The use of remote sensing was discussed as a feasible method of monitoring certain indicators, with the notion that where feasible and warranted, satellite data should be verified through on-ground monitoring.

# Attachment A

## Wetland Indicators Workshop Report

### 4.2 Wetland classification and building the indicators framework

The initial level of classification is related to geographic division. Following this, wetlands are classified based on the dominant nature of the most prominent ecological function. The three wetland types used for the purposes of the workshop are:

- lacustrine wetlands;
- palustrine wetlands; and
- groundwater wetlands.

Lacustrine wetlands are water dominated, although they may have fringing vegetation. There are few lakes in Queensland, making the type easy to identify. Palustrine wetlands are vegetation dominated and there is much more variation in the geomorphic setting and disturbance of these wetlands compared to lacustrine wetlands. Groundwater wetlands considered for this exercise were artesian water and underground water.

### 4.3 Generic and specific indicators

The workshop discussion resolved that the framework of indicators would include:

- a generic suite of indicators applicable to all

wetlands; and

- a set of indicators tailored for subtypes of wetlands within defined climatic regions.

It was noted that the generic set of indicators may prove useful as descriptive indicators, in that they could identify elements that would produce expected ecological services or functions.

The process of developing indicators for lacustrine and palustrine wetlands involved constructing a conceptual model of a wetland, then using this model to identify a list of potential indicators. Following this, conceptual models were constructed for subtypes of wetlands, with the key features, pressures and a list of initial indicators for these sub-types discussed.

Through the process of working on conceptual models and sets of indicators for sub-types and climatic zones, generic indicators applicable to all wetland types may be identified. Figure 1 illustrates an indicator specification.

In addition to the requirement of a specific framework of indicators for different wetland sub-types, it was noted that individual indicators may require specific knowledge and interpretation for different wetland types, subtypes and climatic regions.

**Figure 1. Indicator specification.**

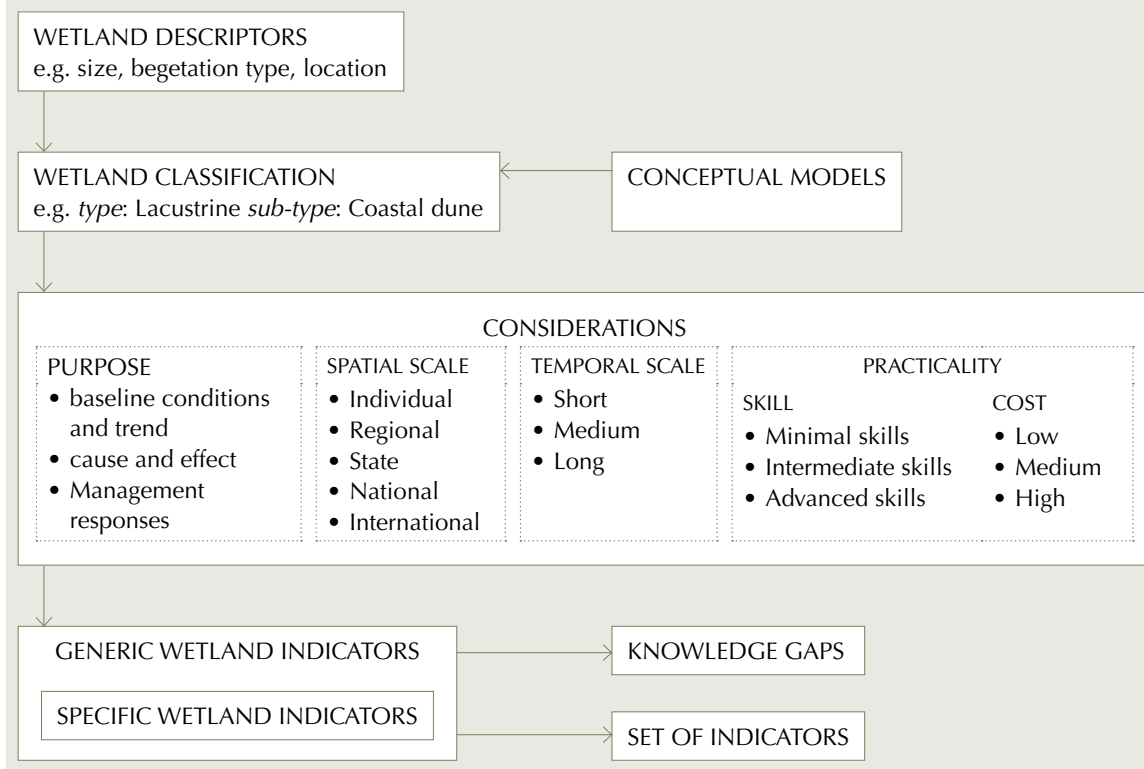
| Generic indicators for all wetlands<br>e.g. surface water area (m2)                                                                                                                                                |                                             |          |          |                                                                                                                                                                                                                    |          |                  |          |                                                                                                       |          |          |       |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------|----------|----------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|------------------|----------|-------------------------------------------------------------------------------------------------------|----------|----------|-------|
| Lacustrine wetland indicators<br>e.g. fish population species and abundance                                                                                                                                        |                                             |          |          | Palustrine wetland indicators<br>e.g. vegetation type and structure                                                                                                                                                |          |                  |          | Groundwater wetland indicators<br>e.g. stygofauna abundance                                           |          |          |       |
| Identified Lacustrine wetland sub-types: <i>coastal dune lakes, terminal depression lakes, depression lakes (inland, non-arid), artificial lakes, arid-zone, saltwater, river-fed lakes, and inland salt lakes</i> |                                             |          |          | Identified Palustrine wetland sub-types: <i>coastal forest swamps, coastal sedge swamps, inland arid-zone swamps, artificial bore drains, natural groundwater springs, herbs and forbs, and freshwater meadows</i> |          |                  |          | Identified Groundwater wetland sub-types: <i>karst, fractured rock, alluvial including hyporheic.</i> |          |          |       |
| Sub A                                                                                                                                                                                                              | Sub A                                       | Sub A    | Sub A    | Sub A                                                                                                                                                                                                              | Sub A    | Sub A            | Sub A    | Sub A                                                                                                 | Sub A    | Sub A    | Sub A |
| Sub B                                                                                                                                                                                                              | Sub B                                       | Sub B    | Sub B    | Sub B                                                                                                                                                                                                              | Sub B    | Sub B            | Sub B    | Sub B                                                                                                 | Sub B    | Sub B    | Sub B |
| Sub C                                                                                                                                                                                                              | Sub C                                       | Sub C    | Sub C    | Sub C                                                                                                                                                                                                              | Sub C    | Sub C            | Sub C    | Sub C                                                                                                 | Sub C    | Sub C    | Sub C |
| Sub D                                                                                                                                                                                                              | Sub D                                       | Sub D    | Sub D    | Sub D                                                                                                                                                                                                              | Sub D    | Sub D            | Sub D    |                                                                                                       |          |          |       |
| Sub E                                                                                                                                                                                                              | Sub E                                       | Sub E    | Sub E    | Sub E                                                                                                                                                                                                              | Sub E    | Sub E            | Sub E    |                                                                                                       |          |          |       |
| Sub F                                                                                                                                                                                                              | Sub F                                       | Sub F    | Sub F    | Sub F                                                                                                                                                                                                              | Sub F    | Sub F            | Sub F    |                                                                                                       |          |          |       |
| Region 1                                                                                                                                                                                                           | Region 2                                    | Region 3 | Region 4 | Region 1                                                                                                                                                                                                           | Region 2 | Region 3         | Region 4 | Region 1                                                                                              | Region 2 | Region 3 |       |
| Sub F                                                                                                                                                                                                              | Sets of indicators for subtypes of wetlands |          |          |                                                                                                                                                                                                                    | Region 1 | Climatic regions |          |                                                                                                       |          |          |       |

## 5 The Indicator Framework

### 5.1 Wetland indicator identification framework

One of the major outcomes of the workshop was the development of a framework (Figure 2), which will provide a pathway from wetland descriptors to a set of appropriate indicators to address the needs of the monitoring task.

**Figure 2. Indicator framework.**



# Attachment A

## Wetland Indicators Workshop Report

### 5.2 Wetland indicator considerations – a worked example

A worked example is shown in Figure 3. The example given, of the measurement of water cover (m2), shows that the same indicator may be applied in different ways for a number of purposes, and further, that the different purposes will highlight different determining factors. An appropriate assessment method cannot be decided until these defining factors are identified.

For example, for the purpose of assessing baseline

condition and trend\*, the information required would relate to a small temporal and spatial scale, and would be best served by on-ground testing by community members or local government. However, in order to assess drivers and change (\*\*), or to identify management actions (\*\*\*), the temporal and spatial scales of required information would presumably be greater, and may be better served through remote sensing. This would not necessarily require a high level of skill, but would most likely incur significantly greater cost.

The shaded boxes indicate pertinent levels of

**Figure 3. Worked example of applying the matrix for a set indicator over a range of purposes.**

| Determining Factors        | Classification |   |    | Purpose |     |     | Spatial Scale |     |    |     |     | Temporal Scale |   |   | Practicality |     |     |      |   |   |
|----------------------------|----------------|---|----|---------|-----|-----|---------------|-----|----|-----|-----|----------------|---|---|--------------|-----|-----|------|---|---|
|                            |                |   |    |         |     |     |               |     |    |     |     |                |   |   | Skill levels |     |     | Cost |   |   |
| Parameters                 | L              | P | GW | C&T     | D-Δ | Mgt | Ind           | Reg | St | Nat | I/N | S              | M | L | Bas          | I/M | Adv | L    | M | H |
| Water cover*<br>Method A   |                |   |    | *       |     |     |               |     |    |     |     |                |   |   |              |     |     |      |   |   |
| Water cover**<br>Method B  |                |   |    |         | **  |     |               |     |    |     |     |                |   |   |              |     |     |      |   |   |
| Water cover***<br>Method C |                |   |    |         |     | *** |               |     |    |     |     |                |   |   |              |     |     |      |   |   |

application

**Classification**  
**L:** lacustrine  
**P:** palustrine  
**GW:** groundwater

**Purpose**  
**C&T:** baseline condition and trend  
**D-Δ:** driver and change  
**Mgt:** management response

**Spatial Scale**  
**Ind:** individual  
**Reg:** regional  
**St:** state  
**Nat:** national  
**I/N:** international

**Time Scale**  
**S:** short  
**M:** medium  
**L:** long term

**Practicality**  
 • Skill/assessment facility  
**Bas:** basic  
**I/M:** intermediate  
**Adv:** advanced

• Cost  
**L:** low  
**M:** Medium  
**H:** high

## 6 Lacustrine Wetlands

### 6.1 Lacustrine conceptual model

This conceptual model aims to be a generic description which can be modified for different regions and wetland subtypes. It is represented diagrammatically in Figures 4 (wet phase) and 5 (dry phase).

---

#### Lacustrine wetlands

---

##### Key Features

---

##### Physical

- Surface area  $\geq 8\text{ha}$
  - If  $< 8\text{ha}$ , then must be deeper than 2 metres (at deepest point when full)
  - Sediment substrate
  - Can have connectivity with other water bodies (leading to species dispersal)
  - Spatial complexity/ habitat complexity
  - Submerged debris as habitat
  - Bathymetry – shape of lake bed
  - Presence/absence of islands within the water body
- 

##### Hydrology

- Water dominated
  - Water source: groundwater/overland flow/precipitation/channel overflow
  - Water inflow regime: pulsing of water, or single large influx event
  - Evaporation
  - Mixing by wind
  - Velocity/water movement/flow rates/flushing
  - Stratification
  - Wetting/drying – fluctuation may occur
- 

##### Physico-chemical

- Water regime and chemistry
- Nutrients input: overland flow/allochthonous/groundwater
- Sediment and nutrient input
- Water quality
- Ionic composition

- Organic matter
  - pH
  - Light climate variable – clear/turbid/tannin stained/stratification
  - Interaction between plants and light climate
- 

##### Biota

- Without emergent vegetation over most of the wetland extent
  - Submerged vegetation/ macrophyte vegetation (depth limited – generally  $< 3\text{m}$ , but can be much deeper if turbidity is very low)
  - Riparian buffer zones
  - Allochthonous input (organic material produced by photosynthesis outside the wetland e.g. leaf litter)
  - Autochthonous input (organic material produced by photosynthesis within the wetland e.g. aquatic plants)
  - Primary production – light/temperature controlled
  - Macrofauna – in and on water (birds, fish, turtles, frogs etc)
  - Nesting birds – affecting nutrients
  - Macroinvertebrates (grazers at edges)
  - Extent (depth and duration of water affecting vegetation)
  - Dynamic exchange between benthic, littoral, and pelagic zones
  - Algae
  - Phytoplankton
  - Algal ‘bath tub rings’ at the water line, particularly in arid zones
  - Attached or benthic algae
  - Zooplankton
  - Bacterioplankton
  - Autotrophic
  - Heterotrophic
  - Benthic microbiota
- 

##### Processes

- Sedimentation
- Biogeochemical cycling of nitrogen, phosphorus and carbon
- Temporal fluctuations (including seasonal/cyclical)
- Bush fire: successional phenomena – life cycle phases – hydrological variation giving successional

# Attachment A

## Wetland Indicators Workshop Report

ecology and morphology

- Set of meta-stable states or continuous variation

### Drivers

- Hydrology
- Water depth
- Groundwater exchange
- Source
- Evaporation
- Surface run-off
- Connectivity
- Seasonality
- Duration and frequency
- Flushing regime
- Light
- Turbidity
- Stratification
- Tannins/colour
- Water quality
- pH
- Conductivity and ionic composition
- Nutrients and organic matter
- Hardness
- Dissolved oxygen
- Habitat complexity
- Within lake microhabitats
- Lake geomorphology and shape
- Landscape/catchment position
- Sediment/substrate composition

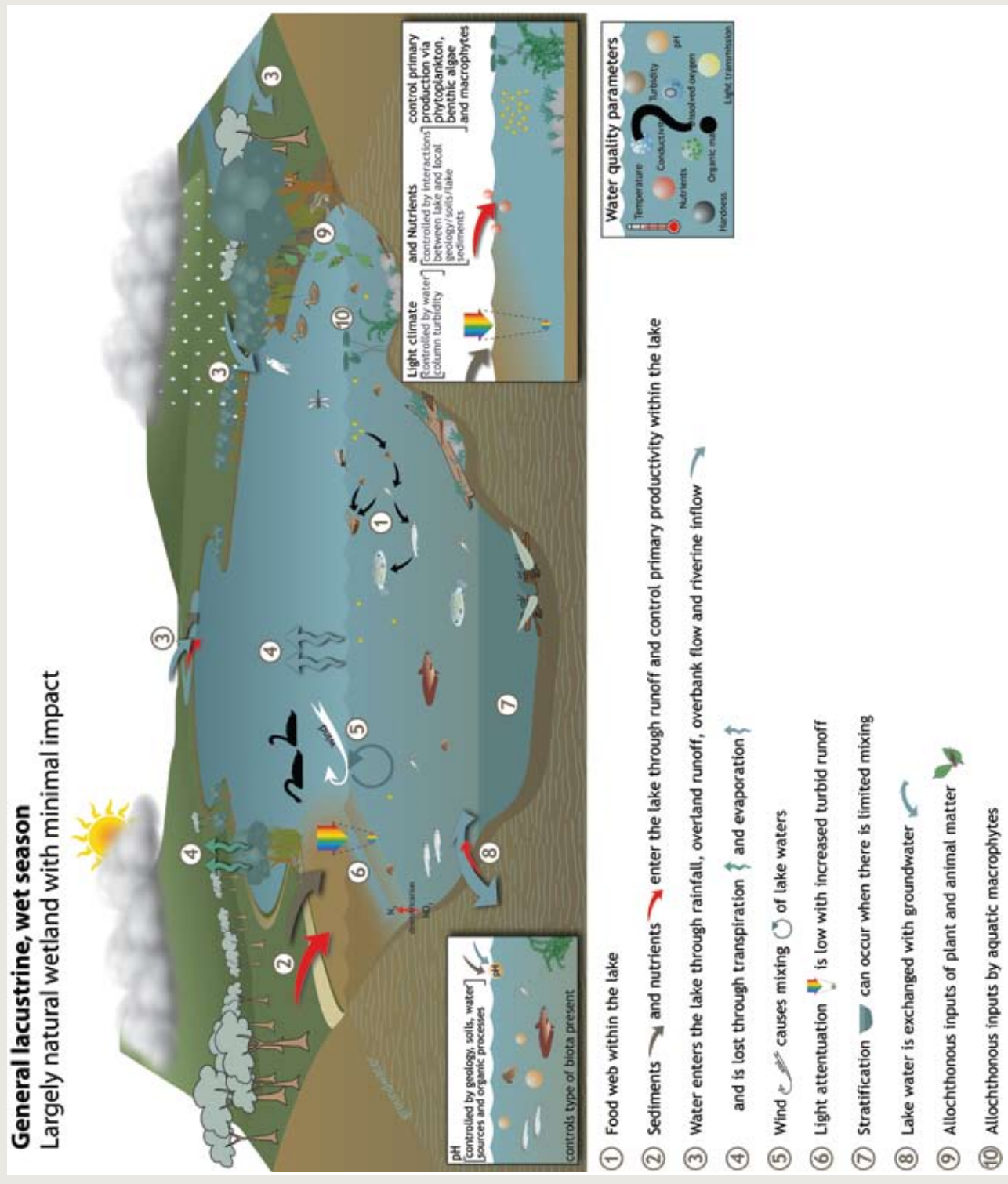
### Pressures

- Biota (cover and type)
- Water regime
- Timing
- Flow duration, size, frequency
- Acidic conditions
- Waterbody margins
- Nutrients
- Deposition
- Weeds
- Exotic animals
- Human impacts
- Lake bed cropping/grazing when dry

### Potential Indicators

- Photic depth
- Nutrient status
- Salinity
- Aerial extent (remote sense based) fluctuations, aerial extent of wetted area
- Turbidity (couple remote sensing and on-ground data at selected sites)
- Fringing vegetation fluctuations in response to impacts e.g. river red gum deaths
- Changes in amount of surface area that falls into certain categories - defined by ratio between euphotic depth and total depth.
- Oxygen profile - the point at which oxygen falls below thresholds for diverse macroinvertebrate populations
- Those that do/don't have enough oxygen all day, and those that have enough for part of the day
- Weediness (proportion of weeds in aquatic vegetation)
- Biota - diversity and abundance
- Spatial extent, specifically in terms of existence value.
- Spatial extent and events which may change the surface area:
- Water quantity
- Hydrological fluctuations
- Water quality
- Range of ecological functions
- Trophic status
- Chlorophyll a
- Algal blooms
- Extent - 'reference extent model' for types of lacustrine
- Hydrological regime – disturbed/modified/ deviation from natural
- Deviation from expected hydrology
- Deviation from expected riparian vegetation
- Landscape function analysis: catchment contribution, erosion, irrigation
- Use of the wetland (for recruitment, roosting, moulting, migration stopover)

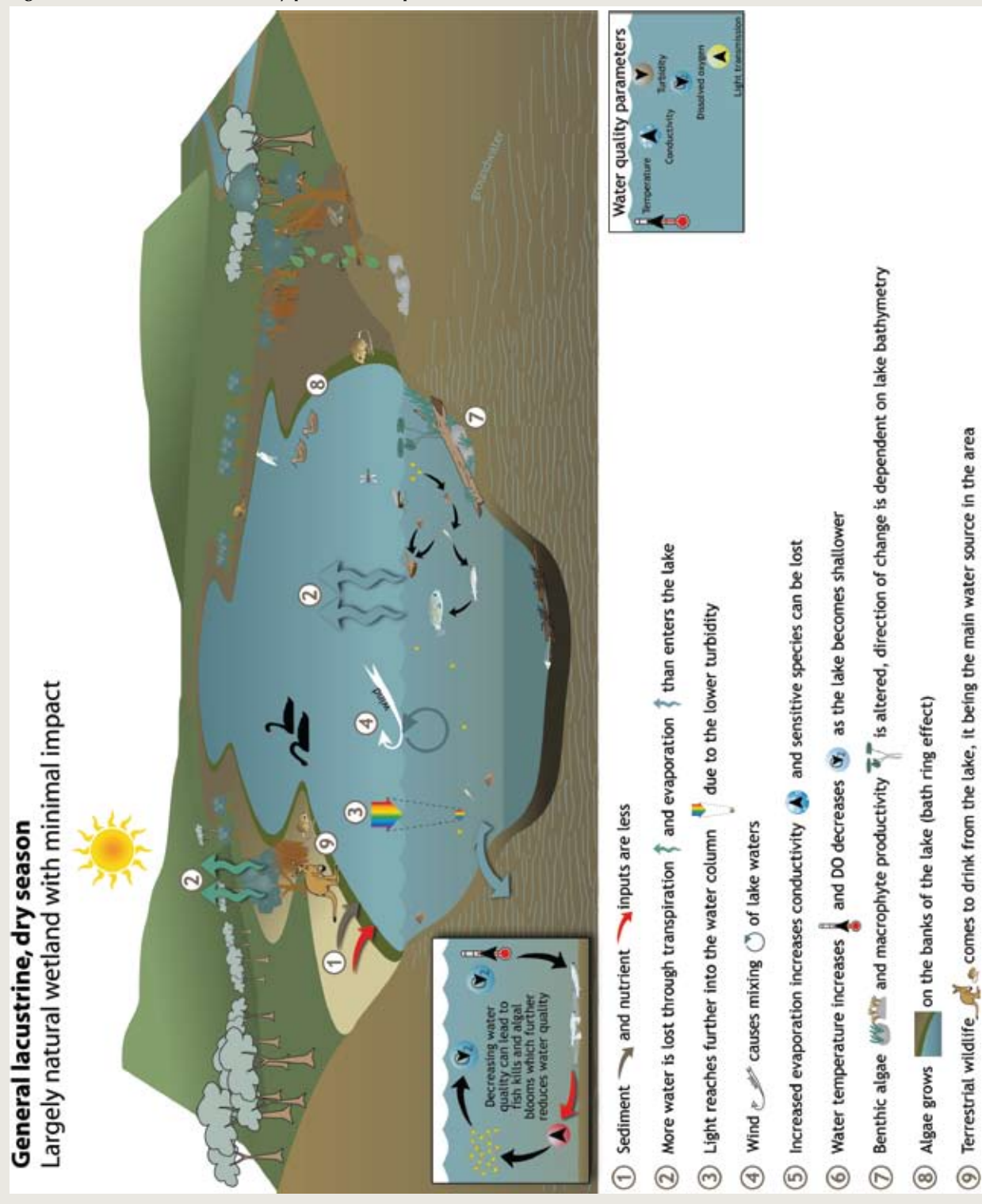
Figure 4. Lacustrine wetland (wet phase) conceptual model



# Attachment A

## Wetland Indicators Workshop Report

Figure 5. Lacustrine wetland (dry phase) conceptual model



## 6.2 Lacustrine sub-type conceptual models

Conceptual models were constructed for the following lacustrine wetland sub-types: coastal dune lakes, terminal depression lakes, depression lakes (inland, non-arid), artificial lakes, arid-zone saltwater river-fed lakes, and inland salt lakes. Illustrations for these wetland types are in Appendix F.

### 6.2.1 Coastal dune lakes

eg. Blue Lake, Stradbroke Island (window lake)

#### Key Features

- **Physical**
  - High stability, low variability
  - Regional watertable fluctuates slowly
  - High transparency (light may reach bottom)
  - Silica sand substrate
  - Deep
  - Majority of three dimensional habitat is emergent macrophytes
- **Hydrological**
  - Groundwater exchange
  - Precipitation runoff and percolation through sand
- **Physico-chemical**
  - pH slightly acid 5-6
  - Conductivity very low (<100µS/cm (Na, Cl))
  - pH of groundwater 7.5 (key to ecology)
  - Low nutrients
  - Low productivity
- **Biota**
  - Adapted to slightly acidic water
  - Low species richness and abundance (low biomass, rare species)

#### Pressures

- Water regime change
- Acidic condition change
- Nutrient status change
- Vegetation clearing and dune movement
- Tourism

#### Ecological responses

- pH and conductivity change could equate to a change in community structure, and loss of the current ecological system
- Change in water level can lead to change in three-dimensional habitat (reeds), which supports biota
- Loss of unique organisms and influx of ubiquitous organisms

#### Knowledge gaps

- Acidity (not pH) – an understanding of the conditions that lead to acidity.
- Infiltration effects

#### Measurement

- There is a possibility of remote sensing to show the extent of the water body.

### 6.2.2 Terminal depression lakes

#### Key Features

##### Wet phase

- **Physical**
  - Shallow 0-2 m, large extent (>8 Ha)
  - Unlikely to stratify (low mixing)
  - 2.5 m sediment, up to 100,000 years deposition
  - Channel network, overflow outlet
- **Hydrological**
  - Main input is river inflow containing nutrients, carbon, sediment and organisms
- **Physico-chemical**
  - Highly turbid (light penetration 0-2 cm)
- **Biota**
  - Autotrophic at margins (primary producers: algae, plants)
  - Heterotrophic in main water body (consumers)
  - Large populations of birds and fish

##### Dry phase

- **Physical**
  - Large areas of bare cracking clays

# Attachment A

## Wetland Indicators Workshop Report

- Soil turnover (important)
- Hydrological
- Can dry completely

### • Biota

- Aquatic organisms take refuge in the sediments
- Increase in terrestrial fauna
- Lignum becomes habitat for terrestrial animals, including ferals

---

### Pressures

- Hydrological
- Quantity and duration of water retention has the most significant effect
- Flow regime change
- Reduced extent
- Reduced waterbird, fish populations
- Reduction in amplitude and frequency of flows
- Sedimentation change

---

### Indicators

- Hydrological regime: temporal and spatial
- Model the relationship between inflows and extent of water body
- Vegetation extent and structure, lignum regeneration
- Breeding success of colonial waterbirds
- Fish population species and abundance
- Water temperature and quality
- Total grazing pressure

---

## 6.2.3 Depression lakes (inland, non-arid)

### Key Features

- Depression in the floodplain

### Wet phase

#### • Physical

- 8-9m deep
- Depositional environment (fine sediment substrate)
- Can have levees
- At low water levels, the process of wind re-suspension of bottom sediments is significant

- Habitats reset by large overbank flow events

#### • Hydrological

- Stratification can occur
- Sources: local storm events (direct precipitation and overland flows), overbank flows from local channels (less frequent but can be largest)
- Groundwater interaction
- Seasonal draw down
- Influenced by local geography (height of surrounding landscape) and access to overbank flows

#### • Physico-chemical

- Variable turbidity
- Turbidity influenced by nature and frequency of overbank flows

#### • Biota

- Very productive - biota, fish, birds, turtle etc
- High diversity
- Fringe riparian vegetation
- Macrophyte beds and emergent vegetation in the littoral zone

### Dry phase

#### • Physical

- Settling of sediment in bottom of depression, resulting in changes in the bathymetry

#### • Hydrological

- No open water

#### • Physico-chemical

- Dissolved oxygen <8% saturation
- Organic substrate becomes anoxic

#### • Biota

- Floating aquatic weed infestations
- Change in faunal composition to more tolerant taxa

---

### Drivers

- Sediment and nutrient loads and nature of delivery
- Hydrological regime including groundwater (inflow/outflow/volume)
- Water quality
- Timing of inputs
- Connectivity with other waterbodies

- Aquatic plant community (including phytoplankton and algae)

---

#### Indicators

- Open water coverage
  - Changes in aquatic fauna and flora composition and abundance
  - Light
  - Dissolved oxygen
- 

### 6.2.4 Artificial lakes

e.g. Water supply dam

The environmental and ecological values of this lacustrine sub-type are a low priority, so position within the catchment/landscape was not assessed.

#### Key Features

##### Full dam

- Large impounded surface area
- Mixing (by wind)

##### Low dam

- Settling of sediments behind dam wall
  - Reduction in biota composition and abundance
  - Increased grazing pressures around dam margins leading to nutrient loading
- 

#### Pressures

- Hydrological regime (raising and lowering of dam level)
- 

#### Drivers

- Function e.g. water supply (as opposed to environmental value)
  - Level of function (potable vs. irrigation)
  - Ability to support threatened species
  - Hydrological regime (volume and timing of filling and release)
- 

#### Responses

- Water quality degradation
  - Increase in algae and nutrients
  - Increase in turbidity
  - Decrease in biota
- 

#### Indicators

- Water quality

- Biota composition
  - Indicators specific to threatened species
  - Spatial extent of wetted area (remote sensing)
- 

### 6.2.5 Arid-zone saltwater river-fed lakes

#### Key Features

- Large terminal wetlands
  - Three phases: drought/flooding/drying
  - High evaporation rates
  - Low groundwater and rainfall inputs
  - Connectivity to other waterbodies supplies majority of input
  - Low soil permeability
  - Basin shape provides the habitat complexity
  - Salinity gradients govern the biota
- 

#### Drivers

- Climate
  - Rainfall
  - Temperature
  - Wind
  - Lack of high riparian vegetation
  - Hydrology (externally driven)
  - Connectivity
  - Soil type
  - Basin shape
  - Water chemistry
- 

#### Pressures

- Flood harvesting (external to site)
- 

#### Responses

- Extent and duration of inundation
- Vegetative zone shift
- Salinity (more saline)
- Reduction in fish and bird populations

#### Indicators

- Biota at a 'whole of system' scale (fish, waterbirds, plants)
  - Long-term monitoring (due to short term noise)
-

# Attachment A

## Wetland Indicators Workshop Report

### 6.2.6 Inland salt lakes

#### Key Features

- **Physical**
  - Salt crust in dry phase
  - Sand and clay substrate
  - High temperature
- **Hydrological**
  - Low rainfall
  - Highly variable hydrological regime
  - Source: overland flow (groundwater interaction unknown)
  - Filling and drying cycles
  - Physico-chemical
  - Turbidity/salinity cycle
- **Biota**
  - Boom and bust cycles
  - Limited riparian vegetation (e.g. saltbush)

#### Drivers

- **Water quality**
  - Salinity/turbidity cycle
  - Colour
  - pH
  - Temperature
  - Nutrients
  - Dissolved oxygen
  - Light
- **Hydrology (externally driven)**
- **Connectivity**
- **Soil type**
- **Basin shape**
- **Water chemistry**

#### Pressures

- Reduction in filling events (climate change)
- Increased grazing
- Extractive industries (unknown)

#### Indicators

- **Rainfall**
- **Evaporation**

- **Hydrological regime**
- **Biota (invertebrates, fish, waterbirds)**
- **Water quality**
  - Salinity/turbidity cycle
  - Nutrients
  - Dissolved oxygen

## 7 Palustrine Wetlands

### 7.1 Palustrine conceptual models

This conceptual model aims to be a generic description which can be modified for different regions and wetland subtypes. It is represented diagrammatically in Figures 6 (wet phase) and 7 (dry phase).

#### Palustrine wetlands

##### Key Features

##### Physical

- Area is not defined
- Generally shallow (Max depth 2m)
- If water is ponded, it may only be a small amount which often dries up
- Gradual edge/bank

##### Hydrology

- Typically have dominant drying phase
- Sources: groundwater, local, floodplain, riverine
- Groundwater/surface exchange

##### Physico-chemical

- Variable water quality
- Organic loading
- Soil condition is important (peat, acid sulfate soils)

##### Biota

- Vegetation dominated (palms, trees, shrubs, grass/sedges, aquatic vegetation)
- Shrubs (e.g. lignum) in water

- Vegetation usually perennial
- Can be submerged macrophyte beds (but not the only type of vegetation)
- Boom and bust cycles in ephemeral wetlands
- Fauna

---

### Processes

- Allochthonous input (organic material produced by photosynthesis outside the wetland e.g. leaf litter)
- Autochthonous input (organic material produced by photosynthesis within the wetland e.g. aquatic plants)
- Continuum of wetland types from lacustrine to palustrine, at varying stages of filling and drying which may or may not relate to seasonal fluctuations
- Fire (particularly in peat areas)
- Ecosystem services
- Significant number are related to connectivity across water bodies e.g. fish migration (fish breeding area)
- Filtering
- Sediment retention
- Material flux/balance/polishing
- Need to define how long a dry area remains a wetland
- Soil conditions (acid sulfate soils); Peat condition
- Salt water intrusion
- Biogeochemical cycling of nitrogen, phosphorus and carbon
- Flooding

---

### Drivers

- Hydrological regime, periodicity of inundation, seasonal drawdown
  - Fire
  - Connectivity/barriers
  - Sea level rise
  - Feral animals
  - Water quality
  - Salinity
  - Temperature
  - Weeds
- 

### Pressures

- Fire
  - Grazing
  - Climate change
  - Drainage
  - Hydrology changes
  - Hydrological regime
- 

### Potential Indicators

- Extent and structure of groundcover (vegetation health index)
  - Benthic biota
  - Fish kills
  - Organic loading
  - Flow rate in bores and springs
  - Extent
  - Vegetation change
  - Fauna habitat
  - Diversity and abundance of the fauna
  - Critical life stages
  - Health of trees/cover (die back)
- 

### Knowledge Gap

- Extraction, discharge and recharge
-

# Attachment A

## Wetland Indicators Workshop Report

Figure 6. Palustrine wetland (wet phase) conceptual model

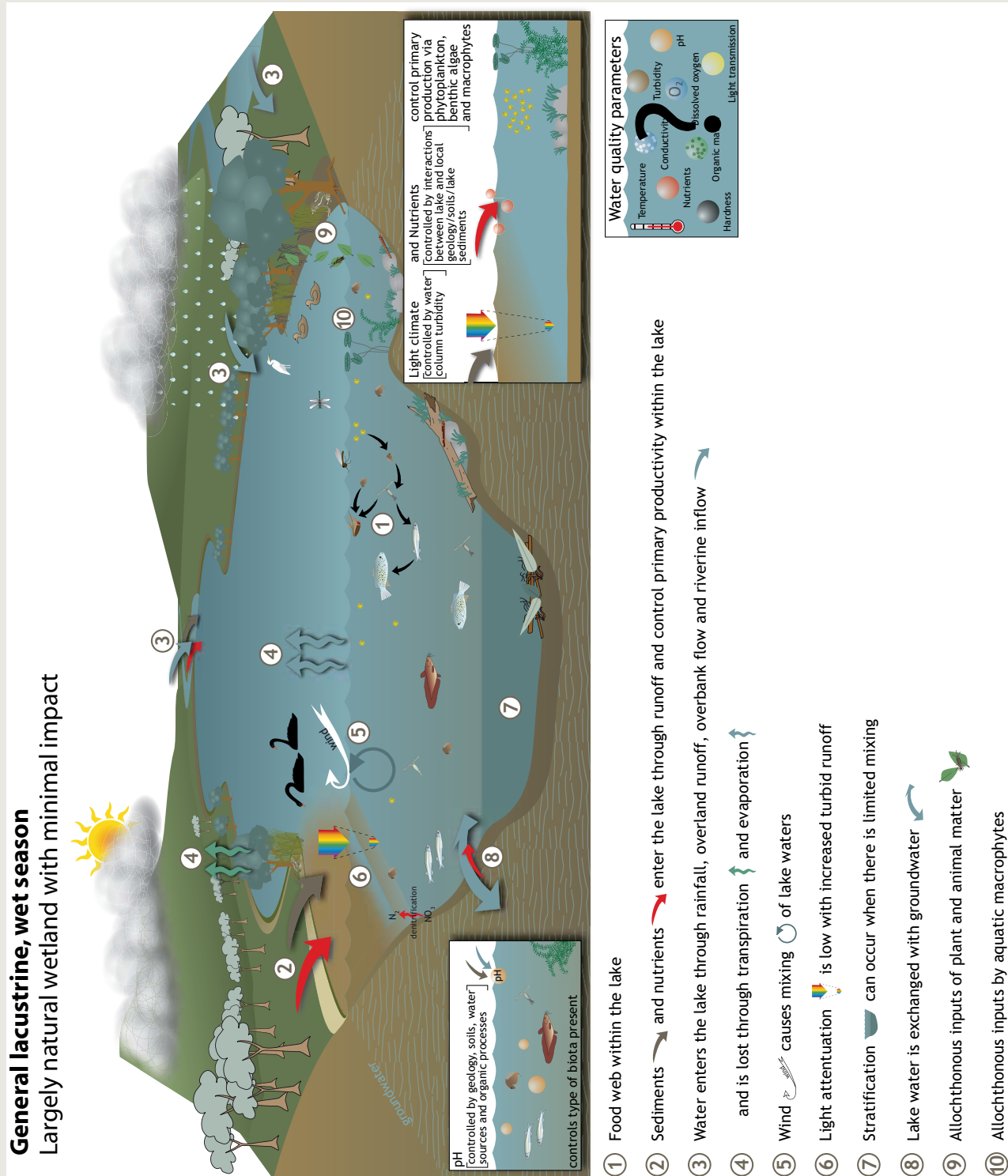
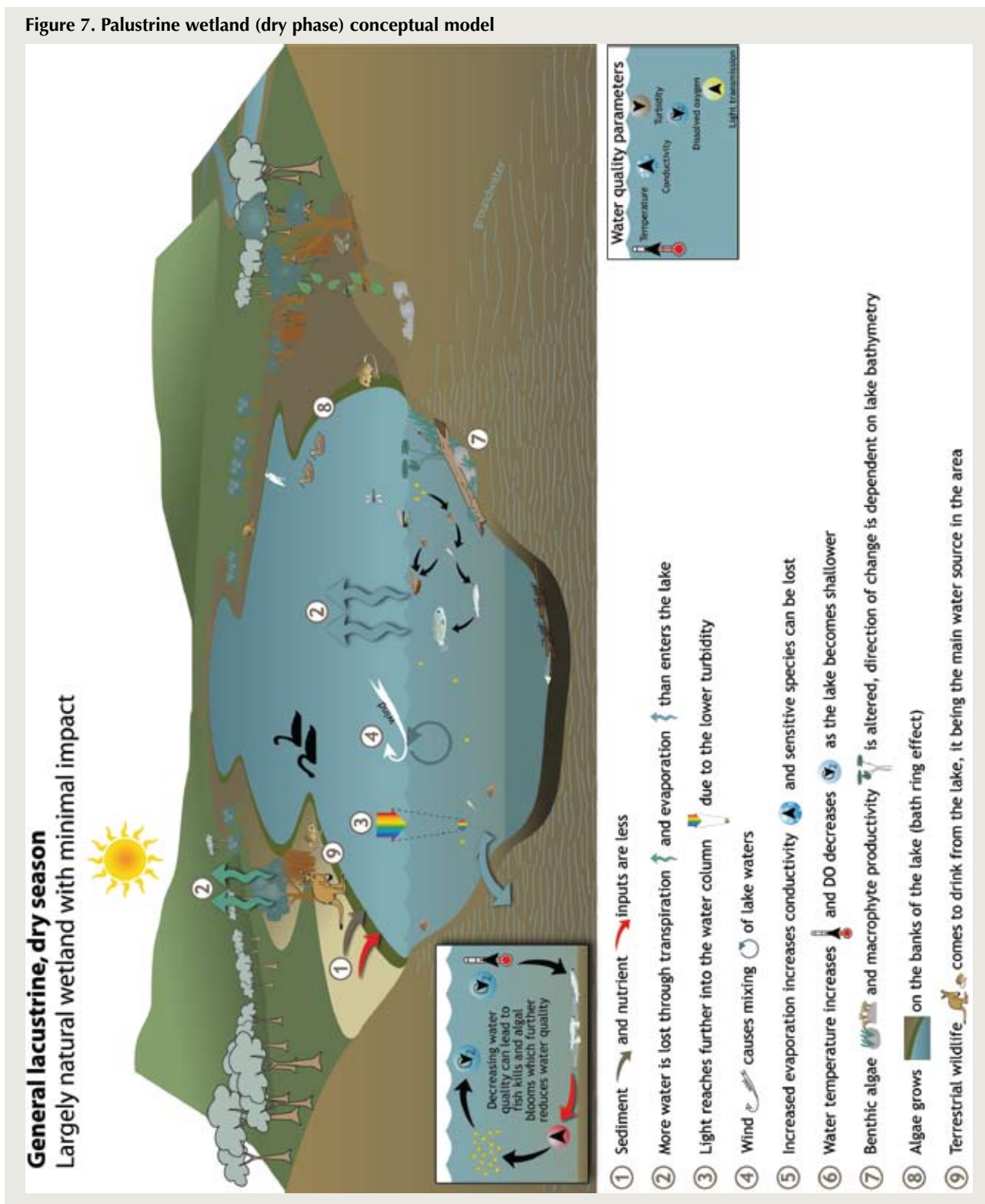


Figure 7. Palustrine wetland (dry phase) conceptual model



# Attachment A

## Wetland Indicators Workshop Report

### 7.2 Palustrine sub-type conceptual models

Conceptual models were constructed for the following palustrine wetland sub-types: coastal forest swamps, coastal sedge swamps, inland arid zone swamps, artificial bore drains, natural groundwater springs, herbs and forbs, and freshwater meadows. Illustrations for these wetland types are in Appendix G.

#### 7.2.1 Coastal forest swamps

e.g. Melaleuca, Casuarina

##### Key Features

###### Physical

- Shallow
- Seasonal inundation
- Located
  - Behind backdunes and saltmarsh
  - Depressions near rivers and estuaries
  - Floodplain depressions
  - Poorly drained lowland
- Can have old creek channels and deep holes
- Bed can be impermeable, excluding groundwater exchange
- Has a peat layer

###### Hydrology

- With/without groundwater inputs
- Short drying phase
- Source: overland flow

###### Physico-chemical

- Nutrients cycling important
- Acid sulfate soils
- Saline ground water
- Influence of high spring tides/flooding

###### Biota

- Dominated by trees
- Good biodiversity (fish, birds, mosquitoes, frogs, reptiles, mammals, insects)
- Melaleucas:
  - Rich source of pollen and nectar for local and migratory birds, insects, bats and

possums

- Koalas feed on leaves
  - Important refuges in drought
- Understorey can be variable – dependant on
  - Water depth
  - Canopy cover
  - Water quality
  - Groundwater
  - pH
  - Salinity
  - Phragmites if saline; Blechnum fern if more freshwater

##### Processes

- Fire
- Hydrological regime: flow, water depth, duration, (seasonally variable)
- Return flows back to river – providing nutrients, colour
- Flood attenuation, water filtering
- Fish habitat, fish nursery areas

##### Drivers

- Hydrology (hydroperiod – extent and frequency of inundation)
- Water depth
- Fire
- Water quality
- Salinity
- pH

##### Pressures

- Clearing
- Draining
- Grazing
- Acid sulfate soils
- Bark removal
- Fire (frequency and intensity)
- Weed invasion
- Channelisation of meanders in creeks
- Saline intrusion
- Rising sea levels

## 7.2.2 Coastal grass-sedge swamps

e.g. Bulkuru sedge

### Key Features

#### Physical

- Large waterbodies (100-1000 ha)
- Old marine plains
- Fine sediments

#### Hydrology

- Marine influenced
- Source: local catchment, overbank flow
- Rarely groundwater exchange
- Seasonal drawdown to drying in some

#### Physico-chemical

- Potential acid sulfate soils

#### Biota

- Treeless
- Emergent and aquatic macrophytes
- Allochthonous dominated
- Low number of fish species, high abundance
- Seasonally highly productive – invertebrates are boom and bust
- Has breeding aggregations (waterbirds)
- Fish nursery

### Drivers

- Hydrology
- Climate
- Rainfall

### Pressures

- Grazing
- Weeds
- Fire
- Connectivity (bundling)
- Tail-water inputs
- Sediment loads
- Climate change
- Feral animals (pigs)
- Organic loading by excess growth of grasses drying dry phase
- Poned pastures (with/without bunding)

## 7.2.3 Inland arid-zone swamps

(Extensive in channel country)

### Key Features

#### Physical

- Geomorphology: variable size and shape
- Shallow
- Defined by vegetation (may also be bare e.g. claypans)
  - Shrub: lignum
  - Grass: cane grass
  - Wooded: Coolibah, River Red Gum, Black Box, Casuarina

#### Hydrology

- Sources: precipitation and local catchment (all types), overbank flow (Shrub, Wooded)
- No groundwater interaction

#### Physico-chemical

- Variable turbidity

#### Biota

- Lignum swamps important for waterbirds
- Boom and bust (invertebrates)
- Important habitat for terrestrial grazers and stock when dry

### Drivers

- Climate (evaporation)
- Soil type
- Connection/isolation from river
- Fire
- Water quality
- Water depth

### Pressures

- Grazing (unsustainable)

### Impacts

- Selective removal of vegetation by stock
- Soil compaction, pugging

### Responses

- Long term changes to vegetation (structure, recruitment, composition)

# Attachment A

## Wetland Indicators Workshop Report

- Loss of fauna habitat leading to reduced recruitment/nesting

---

### Indicators

- Vegetative cover (on-ground; remote sensing not appropriate)
  - Presence/absence of seedlings (giving a health index for vegetation)
  - Pug density (stock rates)
  - Stock track density
  - Stocking rates (stock specific)
  - Impact of native animals (how do we distinguish impacts from livestock?)
  - Presence/absence of palatable species
- 

## 7.2.4 Artificial (bore drains)

### Key Features

#### Physical

- 0-10 ha around the spring or bore head, and may include a long, narrow channel covering many kilometres
- Groundwater (Great Artesian Basin (GAB)) fed systems of purpose-managed drainline
- Refugia

#### Hydrology

- Open water
- Pond or pool on the surface
- Water level constant
- No drying phase

#### Biota

- Floating macrophytes, emergent reeds, sedges
- Surrounding vegetation often contains weeds/ferals

### Drivers

- May mimic natural systems
  - Water quality
    - Temperature
    - Water chemistry
    - Salinity, calcium, sodium
- 

### Pressures

- Cap and pipe program
  - Stock
  - Recreation
- 

### Impacts

- Change floodplain dynamics, flows, and sediment storage
  - Declining water quality in the tailwater
  - Reduced GAB water pressure
  - Cap and pipe program
- 

### Indicators

- Flow rate and pressure
  - Extent
  - Vegetation change (terrestrial and aquatic)
  - Bird, fish populations
  - Tourist visitation
- 

## 7.2.5 Natural groundwater springs

### Key Features

#### Physical

- Generally isolated and localised systems
- Different types
  - Break of slope (fractured rock)
  - Watertable induced (due to fluctuations in groundwater)
  - Mound springs (mostly fed by artesian water)

#### Hydrology

- Source:
  - Break of slope: local catchment
  - Watertable induced: regional water
  - Mound springs: sub-artesian

#### Biota

- High level of endemic organisms (fish, crustacea, snails, invertebrates)
-

### Drivers

- Hydrology
  - Water quality
  - Extent and structure of vegetation
  - Extent of inundation area
- 

### Pressures

- Mound springs:
    - Grazing (domestic, native, feral)
    - Agricultural development
    - Fire
    - Tourism
    - Drawdown (agricultural, mining)
    - Excavations and modifications
- 

### Indicators

- Flow rate
  - Salinity (water quality)
  - Temperature
  - Flow extent/inundation area
  - Wetting/drying cycles
- 

## 7.2.6 Herbs and forbs

### Key Features

#### Physical

- Small
- Shallow (<0.5 m deep)
- Low relief
- Clay/sand base
- Seasonal/intermittent

#### Hydrology

- Source: precipitation
- Generally no interaction with groundwater

#### Physico-chemical

- Freshwater

#### Biota

- Herb dominated, annuals
  - Turnover in species
  - Refugia from predation
- 

### Pressures

- Grazing and cutting
  - Pugging
  - Cropping and leveling
  - Weed invasion
  - Fire
- 

### Indicators

- Vegetation assessment (wet and dry phases)
  - Weediness
  - Grazing pressure (remote sensing)
- 

## 7.2.7 Freshwater meadows

### Key Features

#### Physical

- Coastal, close to tidal influences
- Similar to 'Herbs and Forbs'
- <0.5 m deep

#### Hydrology

- Exist as a result of water logging (groundwater)
- Localised run-off

#### Physico-chemical

- Periodic inundation by salt water
- High organic matter
- Potential for acid sulfate soils

#### Biota

- Mangroves and saltmarsh nearby
  - Fish nursery
  - Uniform grass (herbs and forbs) growth
-

# Attachment A

## Wetland Indicators Workshop Report

### Drivers

- Hydrologic regime
- Vegetation gradient (terrestrial to marine)

### Pressures

- Human impact (people, urbanisation, grazing)
- Soil compaction
- Plant loss
- Nutrients increase
- Increase in open water
- Weeds
- Climate change (sea level rise)
- Vegetation clearing
- Cultivation
- Fire
- Pondered pasture

### Indicators

- Ground cover change and extent
- Benthic biota
- Fish kills

This wetland sub-type was subsequently merged with the Herbs and Forbs sub-type.

## 8 Groundwater

### Significant knowledge gaps exist

#### Key Features of underground wetlands

i.e. wetlands without surface breakout

#### Physical

- Different types of underground wetlands
- Subterranean karst
- Fractured rock
- Alluvial hyporheic (the wetted interstitial zone among sediments below and alongside rivers)
- Porous

#### Biota

- Low species richness
- Unique biota (stygo fauna - fauna that live within groundwater systems)
- Some species are ancient surface species

#### Processes

- Provides wildlife refuge where it is a break out feature e.g. bird habitat
- Denitrification
- Nutrient transfer (rivers)
- Filters contaminants before delivery to groundwater/surface water

#### Pressures

- Water extraction influences the maintenance of supplies
- Seawater intrusion leading to impacts on the stygo fauna and reduction of porosity
- Chemical pollution

#### Indicators

- Groundwater regime
- Water quality (saline pollution)

## 9 Other Key Discussion Points

### 9.1 Characterising wetlands

Managing wetlands requires setting a management purpose. The workshop facilitated a discussion of the options of understanding and defining baseline condition by use of:

- pristine 'reference' condition as the basis of comparison;
- ecological character of a wetland based on identified values; or
- an ecosystem services approach.

Reference condition was discussed in detail. Ecological character and ecosystem services were mentioned but not expanded upon as an alternative approach to the reference condition approach.

#### 9.1.1 Reference condition

- Use of reference condition is a challenge because it downplays the intrinsic value of the majority of wetlands which are modified rather than pristine. The reference catchment may be on a different flooding trajectory to the sampled catchment, and therefore not provide an accurate reference. It was noted that a very broad definition of reference can be used, which will identify large impacts, or alternatively, a higher level of detail in the reference model could be used to pick up more subtle changes.
- Within the referential approach, there is a need to account for natural envelopes of variability, equally important in temporal elements. There is a need to know where the lake is placed in the sequence of natural variability. If not, the level of variability will be much higher, making the act of detecting human impact more difficult.

#### 9.1.2 Value judgements – setting environmental values for management

##### Assessment and value judgements

The concept of condition assessment requires a value judgement. It was argued that the status of a suite of elements may also lead to a definition of condition.

It was then noted that the condition of the wetlands needs to be expressed in terms of its ecological character, with the ability to indicate change, and hence warn if an element is at risk. The notion of a value judgement was revisited as the loss of one element may result in gaining another. A judgement on which element is to be prioritised and valued would then have to be made. It was suggested that the referential wetland may then not be appropriate as values need to be defined, rather than simply taken from the reference/wetland.

### 9.2 Risk management approaches

Results of an assessment of extent and condition could be used to inform a risk management strategy. Monitoring through periods of vulnerability, and around thresholds, for example may provide information on the level of risk, and may be used to trigger proactive mitigation measures.

### 9.3 Remote methods or ground testing – when and why?

The monitoring/assessment methodology used will need to be tailored to the scale, purpose and skill level, funds, and knowledge base of the responsible party. While remote sensing is appropriate, and cost and time-efficient in some cases, it may provide inaccurate or incomplete information in others. It was noted that, where possible, remote (satellite) data should be 'ground-truthed' through on-ground field testing or survey.

It was also noted that in order to determine the baseline condition of a wetland, monitoring must be repeated over a significant period of time (this will depend upon the wetland, the indicator and the geographic location and climate). The need for multiple monitoring events in order to determine the condition was acknowledged.

### 9.4 Extent of the wetlands

It is difficult to draw boundaries around wetlands, as their interconnectedness within the catchments, and to other wetlands, is a defining feature of these systems. Indicators of extent were not discussed in detail.

# Attachment A

## Wetland Indicators Workshop Report

### 9.5 Users' needs and capabilities

A key factor in defining a set of appropriate, practical and accurate indicators is heavily reliant on the available level of knowledge and expertise applied throughout the process. The workshop discussions resolved that contextual information and knowledge of key factors, processes, linkages, and the ecological function and cycle of individual wetlands are necessary. Below is a list of the areas of required knowledge:

- Knowledge of the individual wetland with which you are dealing. Factors include stability, position in cycle, temporal scale, and regional climatic and geomorphological overlay.
- Conceptual information of the cycles of types and subtypes of wetlands.
- Periods of vulnerability/thresholds/break points. Monitoring/testing should be conducted during these times.
- The relationship between health and time since flooding.
- Depending on the level of skills required, monitors may need to know the link between patterns and processes.
- Contextual information regarding particular factors. For example, when sampling biota, the maximum bio-productivity of a wetland may need to be known.
- The spatial scale of the entire wetlands, e.g. small wetlands may be remnants of larger wetlands.
- The capacity to relate indicators and measures to existing wetland inventories and knowledge systems.

### 10 Summary

The workshop produced a number of insights around the development of an indicator framework for wetland extent and condition:

- Wetland indicators must have a defined purpose, and be tailored to meet this purpose.
- The level of information required to be produced by the indicator must be defined in terms of temporal and spatial scale.
- The appropriateness of the level of skill required and cost-effectiveness of the assessment methods are critical determining factors in developing an indicator framework.
- There is a risk in using descriptive elements as indicators. In some instances, however, descriptors may be able to function as indicators.
- An indicator framework will include a matrix of generic and specific indicators.
- A level of background knowledge is required, in order to accurately assess the condition and extent of a wetland, with regard to the individual wetland cycle, or regional climatic system.
- Conceptual models will be developed.
- There is a possibility of taking a risk based approach.
- Types of indicators could align with the three elements of pressure, vector, and response.

## 11 Way Forward

The final task of the workshop was to identify mechanisms for on-going participation and a way forward for the program. Below are the key identified mechanisms for the advancement of the programme.

- There is a need for a commitment from the State and Federal Governments in terms of financial and human resource contributions. Further to this it was noted that regional involvement would be integral to this process.
- The conceptual models for the wetland types and sub-types would be further developed with the assistance of specialists before undergoing a peer review process.
- It was suggested that participants be sent the key findings/outcomes of the workshop, and be given the opportunity to comment on the draft report. In order to foster ongoing information sharing and discussion on the topics raised in the workshop, an email network will be established. Possible future small group workshops based around key themes was supported by workshop participants. One desired outcome of this information sharing would be a complete database of potential assessment methods in use throughout Australia.

# Attachment A

## Wetland Indicators Workshop Report

### Appendix A: Workshop Program – June 8 & 9, 2006

#### Day 1

12:00 *Light lunch on arrival*

|       |                                                  |                 |
|-------|--------------------------------------------------|-----------------|
| 12:35 | Welcome and introduction                         | Mary Maher      |
| 1:00  | Queensland Wetlands Programme                    | Peter Macdonald |
|       | Wetlands indicators project/goal of the workshop | Di Conrick      |
|       | Indicators in use throughout Australia           | Bruce Gray      |
|       | Index of wetland condition                       | Janet Holmes    |
|       | Criteria for indicator selection                 | Bruce Gray      |
|       | Indicators literature search                     | Mike Ronan      |
|       | Wetland systems and types/bioregionalisation     | Bruce Wilson    |
| 1:50  | Lacustrine wetlands extent and condition         |                 |

3:00 *Afternoon tea*

3:20 Issues and challenges for defining indicators

4:30 Complete Lacustrine indicators

5:00 Close

7:00 *Dinner*

#### Day 2

8:45 Complete any issues from Day 1

9:00 Wetlands Inventory Database project Mike Ronan

Pressures and threats John Bennett

National picture – Matters for Targets and NLWRA Alana Innes

9:20 Palustrine wetlands extent and condition

10:45 *Morning tea*

11:10 *Complete* Palustrine indicators

11:30 Groundwater wetlands extent and condition

12:15 *Lunch*

1:00 *Complete* Groundwater indicators

2:00 Discussion on proposed indicators

2:50 Synthesis of indicators and links to other wetland types

3:15 *Afternoon tea*

3:30 Discussion

- Recommendations for research and management
- Applicability for national use

4:00 Thanks and close

## Appendix B: Participant List

|   | Delegate          | Organisation                                                                                                  | Jurisdiction          |
|---|-------------------|---------------------------------------------------------------------------------------------------------------|-----------------------|
|   | Angela Arthington | Griffith University                                                                                           | Queensland            |
|   | Donna Audas       | Great Barrier Reef Marine Park Authority                                                                      | Australian Government |
| * | John Bennett      | Environmental Protection Agency                                                                               | Queensland            |
|   | Stewart Blackhall | Department of Primary Industry, Water and Environment                                                         | Tasmania              |
|   | Andrew Brooks     | Griffith University                                                                                           | Queensland            |
|   | Cassie Burns      | WetlandCare Australia                                                                                         | New South Wales       |
|   | Barry Butler      | James Cook University                                                                                         | Queensland            |
|   | Satish Choy       | Department of Natural Resources & Water                                                                       | Queensland            |
|   | Paul Clayton      | Environmental Protection Agency                                                                               | Queensland            |
|   | Lynda Collins     | Department of the Environment, Water, Heritage and the Arts                                                   | Australian Government |
|   | Diane Conrick     | Department of Natural Resources & Water                                                                       | Queensland            |
|   | Alison Curtin     | Department of Environment and Conservation                                                                    | New South Wales       |
|   | Mark Cushing      | Environmental Protection Agency                                                                               | Queensland            |
|   | Jenny Davis       | Murdoch University                                                                                            | Western Australia     |
|   | Louisa Davis      | Department of Natural Resources & Water                                                                       | Queensland            |
|   | Lindsay Delzoppo  | Environmental Protection Agency                                                                               | Queensland            |
|   | Brendan Edgar     | Land & Water Australia                                                                                        | Australian Government |
|   | Steve Elson       | Environmental Protection Agency                                                                               | Queensland            |
| * | Rod Fensham       | Environmental Protection Agency                                                                               | Queensland            |
|   | Paul Frazier      | University of New England, NSW                                                                                | New South Wales       |
|   | Peter Gehrke      | CSIRO                                                                                                         | Queensland            |
| * | Bruce Gray        | Department of the Environment, Water, Heritage and the Arts                                                   | Australian Government |
|   | Margaret Greenway | Griffith University                                                                                           | Queensland            |
|   | Jonathon Hodge    | Environmental Protection Agency                                                                               | Queensland            |
|   | Danielle Hardie   | Department of Primary Industry, Water and Environment                                                         | Tasmania              |
|   | Emma Hawkins      | Lloyd Consulting                                                                                              | Queensland            |
| * | Janet Holmes      | Department of Sustainability and Environment                                                                  | Victoria              |
| * | Alana Innes       | National Land & Water Resources Audit                                                                         | Australian Government |
|   | Roger Jaensch     | Wetlands International - Oceania                                                                              | Queensland            |
|   | Arthur Knight     | Environmental Protection Agency                                                                               | Queensland            |
|   | Paul Lawrence     | Department of Natural Resources & Water                                                                       | Queensland            |
|   | Brad Lewis        | Department of the Environment, Water, Heritage and the Arts/Department of Agriculture, Fisheries and Forestry | Australian Government |

# Attachment A

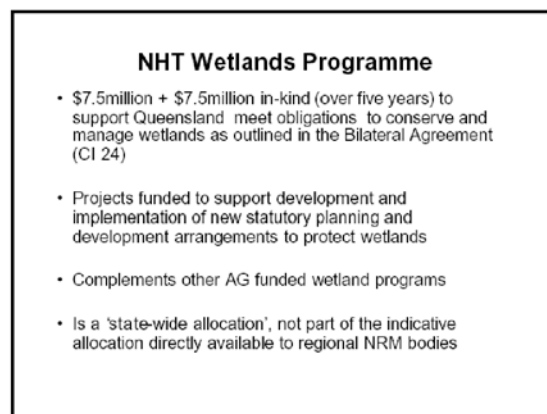
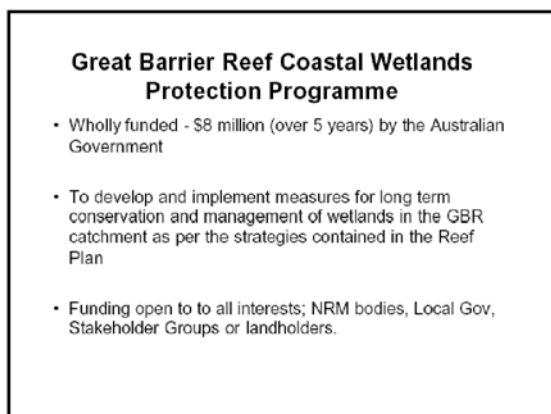
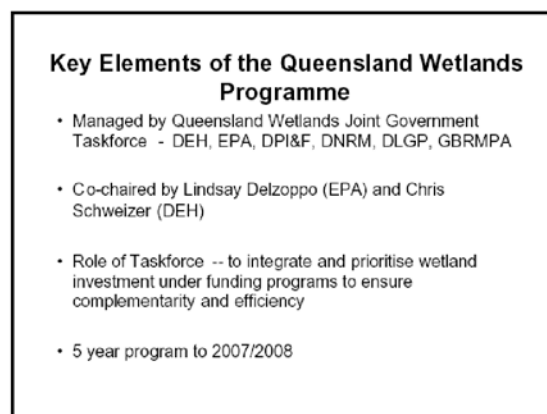
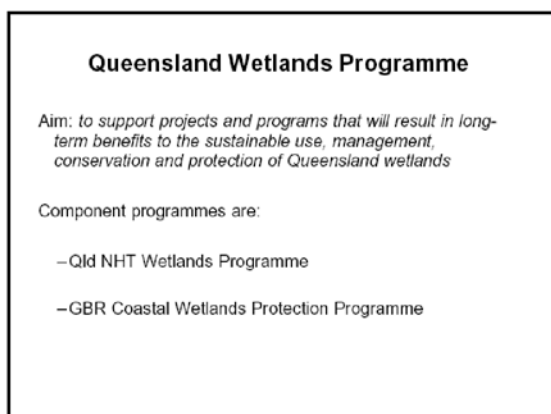
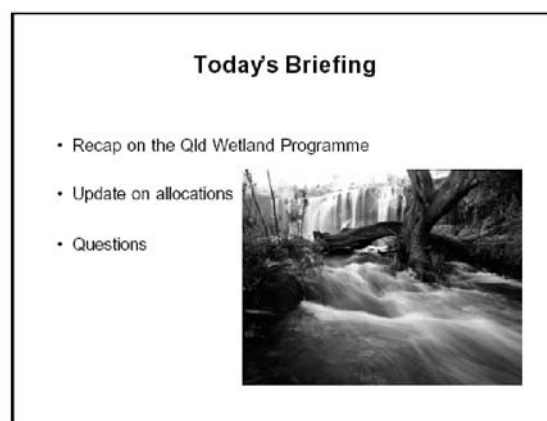
## Wetland Indicators Workshop Report

|   | Delegate              | Organisation                                                  | Jurisdiction          |
|---|-----------------------|---------------------------------------------------------------|-----------------------|
|   | John Lowry            | Environmental Research Institute of the Supervising Scientist | Northern Territory    |
|   | Mike Lyons            | Department of Conservation and Land Management                | Western Australia     |
| * | Peter Macdonald       | Environmental Protection Agency                               | Queensland            |
|   | Mary Maher            | Mary Maher & Associates                                       | Queensland            |
|   | Jon Marshall          | Department Natural Resources & Water                          | Queensland            |
|   | Belinda McGrath-Steer | Department for Environment and Heritage                       | South Australia       |
|   | Glenn McGregor        | Department of Natural Resources & Water                       | Queensland            |
|   | Glen Moller           | Department of Natural Resources & Water                       | Queensland            |
|   | Kay Montgomery        | South East Queensland Catchments                              | Queensland            |
|   | Peter Negus           | Department of Natural Resources & Water                       | Queensland            |
|   | Naomi Nelson          | Department of the Environment, Water, Heritage and the Arts   | Australian Government |
|   | Phil Papas            | Department of Sustainability and Environment                  | Victoria              |
|   | John Patten           | Department of Natural Resources                               | New South Wales       |
|   | David Reid            | Burdekin Dry Tropics NRM Regional Body                        | Queensland            |
| * | Mike Ronan            | Environmental Protection Agency                               | Queensland            |
|   | Glen Scholz           | Department of Water, Land and Biodiversity                    | South Australia       |
|   | Fran Sheldon          | Griffith University                                           | Queensland            |
|   | Holly Smith           | Department of Conservation and Land Management                | Western Australia     |
|   | Brian Stockwell       | Department of Primary Industry & Fisheries                    | Queensland            |
|   | Terri Svensson        | Department of Natural Resources & Water                       | Queensland            |
|   | Jim Tait              | EcoConcern                                                    | New South Wales       |
|   | Lynne Turner          | Environmental Protection Agency                               | Queensland            |
|   | Clayton Vale          | Department of Natural Resources & Water                       | Queensland            |
|   | Simon Ward            | Department of Natural Resources, Environment and the Arts     | Northern Territory    |
| * | Bruce Wilson          | Environmental Protection Agency                               | Queensland            |
|   | Christian Witte       | Department of Natural Resources & Water                       | Queensland            |
|   | Sarah Young           | Environmental Protection Agency                               | Queensland            |

## Appendix C: Presentations

### Presentation C1: Queensland Wetlands Programme

Peter Macdonald, Environmental Protection Agency, Queensland



# Attachment A

## Wetland Indicators Workshop Report

### Initial Round of Funded Projects: NHT Programme

1. **Mapping and classification of wetlands** (\$2 million– EPA leading) GBR catchments due mid 2006, rest mid 2007
2. **Wetland management profiles** (\$278,000– EPA leading) complete
3. **Information review and gap analysis** (DNRW leading) near completion
4. **Monitoring and evaluation strategy for Queensland Wetland Programme** (DNRW leading) complete

### Initial Round of Funded Projects: GBR Coastal Wetlands Programme

1. **Wetland prioritisation Decision Support System** (DEH) due mid 2006
2. **Investigating incentives relevant to wetland conservation** (Coastal CRC) complete
3. **Pilot protection programme for on-ground delivery of wetland conservation and management** (\$2million DEH leading, delivered by consortium of CVA, WCA and ACTFR) in progress
4. **Wetlands display and educational package** – (GBRMPA leading) near completion
5. **Wetlands acquisition** – (EPA leading) in progress
6. **Wetlands module for GLM I** – (DPI&F leading) due mid 2006

### New Projects under NHT Wetlands Programme

1. Impact of proposed regulatory regime for wetland conservation (EPA)
2. Methodology for identifying and mapping ecological, including hydrological connectivity of natural wetlands (EPA)
3. Critical wetland support guidelines (EPA)
4. Soils indicators of wetlands (DPI&F)
5. Wetlands monitoring scoping study (DNRW)
6. Wetlands information capture component (EPA)
7. GBR public reserves management concept (FNQNRM)
8. Improving wetland management in agricultural systems (DPI&F)

### New projects under the GBRCWPP

1. Resourcing wetland GBR Nature Refuge negotiations (EPA)
2. Rehabilitation Guidelines for GBR catchments (DEH)
3. Decision Support System Implementation (DEH)
4. On-ground projects under the GBR coastal wetlands pilot programme

### Both programmes

1. Communications strategy framework (EPA)

### GBRCWPP Pilot Ongoing Projects

- Horseshoe Lagoon (Burdekin-Dry Tropics)
- Healeys Lagoon (Burdekin-Dry Tropics)
- Cungulla (Burdekin-Dry Tropics)
- Georganga (Mackay Whitsunday)
- Lagoon Creek (Wet Tropics)
- Pasture Reserve (Mary Burnett)
- Splitters Creek (Mary Burnett)
- Kinka (Fitzroy Basin)
- Southern Pioneer (Mackay Whitsunday)
- Padaminka (Mackay Whitsunday)
- Stuart Creek (Burdekin-Dry Tropics)
- Serpentine Lagoon (Burdekin-Dry Tropics)
- Thuringowa (Burdekin-Dry Tropics)
- Mulgrave/Russell (Wet Tropics)
- Douglas Shire (Wet Tropics)

### Queensland Wetland Programme updates



## Presentation C2: Wetland Indicators Project/Goal of the workshop

Diane Conrick, Department of Natural Resources & Water, Queensland

Queensland Wetlands Programme  
Scoping study for monitoring  
wetland extent and condition



- Wetlands Inventory Database project
- Monitoring, Evaluation and Reporting Strategy  
–baseline resource condition assessment

### Project Objectives

- Determine appropriate resource condition indicators and methodologies
  - literature search
  - workshop
- Identify resource condition parameters for inclusion in:
  - the Wetlands Inventory Database
  - baseline resource condition assessment for the QWP.
- Advise the National Matters for Target review of wetland indicators

### Workshop Objective

Explore and determine indicators and methodologies for wetland extent and condition for Lacustrine, Palustrine and Groundwater wetlands.

### Workshop Outputs

- Conceptual models
- Indicators and methodologies:
  - Broad-application
  - Specific-application
  - Indicators for development
- Recommendations for research and management
- Applicability for national use



# Attachment A

## Wetland Indicators Workshop Report

### Presentation C3: Indicators in use throughout Australia

Bruce Gray, Department of the Environment and Heritage, Australian Government

#### Victoria

- Index of Wetland Condition (an index of several sub-indices which relate to wetland structure)
- Method has been developed, testing over the next 2 years
- Monitoring: WQ monitoring, Gippsland Lakes IWC, Salinity monitoring in the Wimmera by CMA, Spencer monitored the Murray billabongs

#### Queensland

- Currently ad hoc, not coordinated or comprehensive
- Mainly water quality (field and remote sensing)
- Little consistent time-series
- Mapping and classification project, wetlands inventory
- State of the Rivers, AusRivAS, mound springs monitoring of extent

#### South Australia

- Ad hoc, opportunistic in regions
- Inventory work: rapid assessment, extent and distribution, and condition
- Difficult in arid areas
- Using surrogates to look at long-term changes

#### Tasmania

- TasVeg: vegetation community-based assemblages modelled on the IWC; uses benchmark assessment forms for wetlands
- Tas CFEV: uses condition assessment (expert opinion) and naturalness score; state-wide coverage
- No systematic monitoring
- AusRivAs, Waterwatch, Environmental Flows

#### Western Australia

- Statewide wetland mapping project; broadscale and consistent over 10 years
- Covers invertebrates, birds, WQ, geomorphology, hydrology
- Gaps in Rangelands
- Drafting classification, prioritisation for the State

#### New South Wales

- Developing a new M&E Strategy; currently under review
- IMEF, Hydromonitoring, Waterbirds, Vegetation extent – not collated
- Condition of mound springs
- Wetland mapping
- CMA mapping and prioritisation

#### Northern Territory

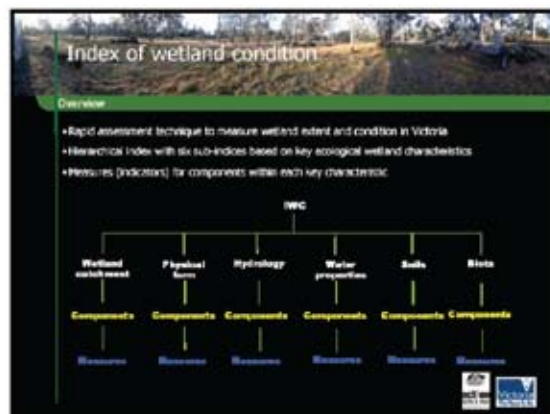
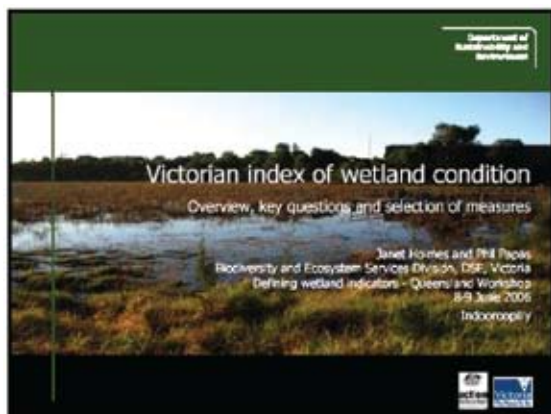
- Inventory work in Douglas, Daly, Greater Darwin
- No real broadscale monitoring
- Longterm monitoring by ERISS in Kakadu
- Beginning to look at integrated condition monitoring using vegetation mapping, WQ, biota, and hydrology

#### Commonwealth (National and International)

- International: Ramsar COP9; Millenium Ecosystem Assessment; rapid assessment report from COP9 (CBD/Ramsar)
- National: MDBC report by Baldwin et al.; Colonial nesting birds surveys (SE: Kingsford; West: Halse; Tropical: Bayliss)

## Presentation C4: Victorian Index of Wetland Condition

Janet Holmes, Department for Sustainability and Environment, Victoria



**Index of wetland condition**  
Key questions in developing the IWC

| Key question                                                          | IWC                                                                                                                                                                                                                                                                                                                         |
|-----------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Why monitor wetland condition?                                        | Legislative, policy and program drivers relevant to Victoria                                                                                                                                                                                                                                                                |
| Who has an interest in monitoring wetland condition?                  | <ul style="list-style-type: none"> <li>DSE, CMAs and other NRM agencies</li> <li>Victorian Commissioner for Environmental Sustainability</li> <li>Citizenship Council of Victoria</li> </ul>                                                                                                                                |
| How will wetland condition monitoring fit into existing NRM programs? | Provides essential input to Victoria's asset-based approach to NRM in regions <ul style="list-style-type: none"> <li>Assessing wetland condition</li> <li>Setting and evaluating against RCTs</li> <li>Identifying threats</li> </ul> Assessing condition of wetlands at State level (Self, enrichment condition reporting) |

**Index of wetland condition**  
Key questions in developing the IWC

| Key question                                           | IWC                                                                                                                                                                                                                            |
|--------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| What is the agreed definition of "condition", "index"? | <ul style="list-style-type: none"> <li>Condition: state of the biological, physical and chemical components of the wetland ecosystem and their interactions</li> <li>Extent: area of a wetland (physical component)</li> </ul> |
| What wetlands will be covered in a monitoring program? | Wetland, non-flowing, naturally-occurring wetlands                                                                                                                                                                             |
| What is the ecological basis for indicator selection?  | Conceptual model based on key wetland characteristics                                                                                                                                                                          |
| Individual indicators or an integrated index?          | Index that covers all key wetland characteristics (based on definition of condition)                                                                                                                                           |

# Attachment A

## Wetland Indicators Workshop Report

**Index of wetland condition**

Key questions in developing the IWC

| Key question                                                          | IWC                                                                          |
|-----------------------------------------------------------------------|------------------------------------------------------------------------------|
| At what spatial scale will monitoring take place?                     | Individual wetland                                                           |
| How can wetland condition be ascertained at regional and State level? | Random sampling of individual wetlands stratified by wetland type and region |
| What is temporal scale for detecting change in condition?             | 10-20 years                                                                  |
| Should monitoring be hypothesis-based or for surveillance?            | Surveillance                                                                 |

**Index of wetland condition**

Key questions in developing the IWC

| Key question                                                                                       | IWC                                                                                                                                                                                                                                                                                                                                                  |
|----------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| What level of sensitivity is required?                                                             | Sufficient to detect significant change                                                                                                                                                                                                                                                                                                              |
| What kind of change should be detected?                                                            | Human-induced (as opposed to natural)                                                                                                                                                                                                                                                                                                                |
| What is the reference benchmark for assessing condition?                                           | The condition of the wetland at the time of European settlement                                                                                                                                                                                                                                                                                      |
| What practical considerations relate to program delivery timelines, resourcing and user-expertise? | Must be able to assess condition: <ul style="list-style-type: none"> <li>• at any time of year (whether wetland is wet or dry)</li> <li>• rapidly (about three hours)</li> <li>• on a single visit</li> <li>• using inexpensive techniques</li> <li>• in a simple, straightforward method</li> </ul> Method must be easy to understand and interpret |

**Index of wetland condition**

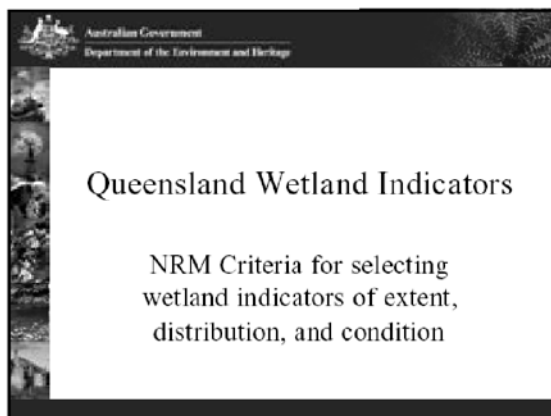
Process for selection of measures

- Identified a set of IWC requirements (based on resolving key questions -above)
- Identified key ecological components for each sub-index
- Identified threats and impacts relating to the component
- Identified possible measures (direct and indirect)
- Evaluated possible measures against IWC requirements

## Presentation C5: Criteria for indicator selection

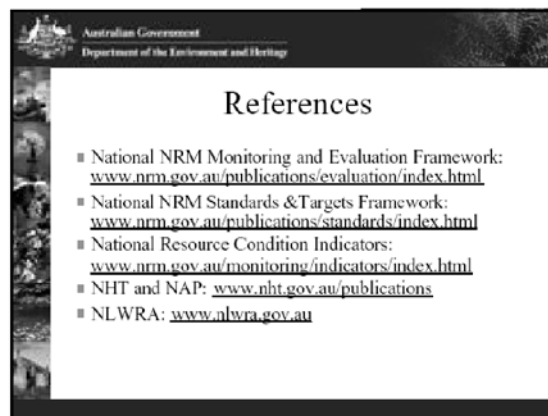
Bruce Gray, Department of the Environment and Heritage, Australian Government



Australian Government  
Department of the Environment and Heritage

### Queensland Wetland Indicators

NRM Criteria for selecting wetland indicators of extent, distribution, and condition



Australian Government  
Department of the Environment and Heritage

### References

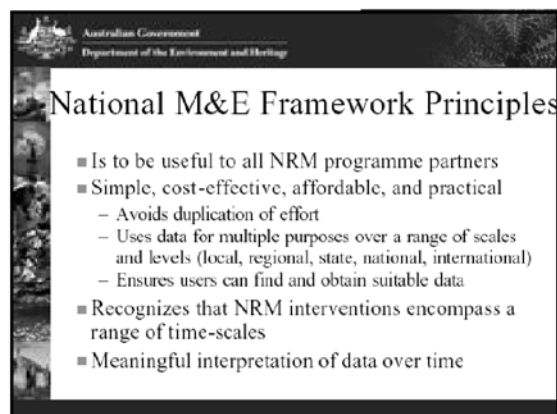
- National NRM Monitoring and Evaluation Framework: [www.nrm.gov.au/publications/evaluation/index.html](http://www.nrm.gov.au/publications/evaluation/index.html)
- National NRM Standards & Targets Framework: [www.nrm.gov.au/publications/standards/index.html](http://www.nrm.gov.au/publications/standards/index.html)
- National Resource Condition Indicators: [www.nrm.gov.au/monitoring/indicators/index.html](http://www.nrm.gov.au/monitoring/indicators/index.html)
- NHT and NAP: [www.nht.gov.au/publications](http://www.nht.gov.au/publications)
- NLWRA: [www.nlwra.gov.au](http://www.nlwra.gov.au)



Australian Government  
Department of the Environment and Heritage

### National NRM M&E Framework

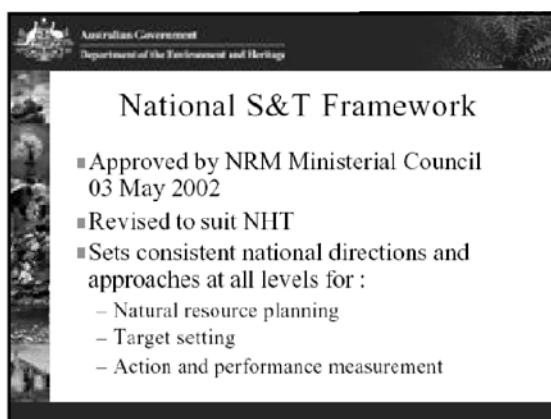
- Approved by NRM Ministerial Council 03 May 2002
- Agreed by all States and Territories
- Provides a structure to monitor and evaluate
  - Natural Resource Condition
  - Program Performance
- Uses the S&T Framework to establish standard indicators and measures



Australian Government  
Department of the Environment and Heritage

### National M&E Framework Principles

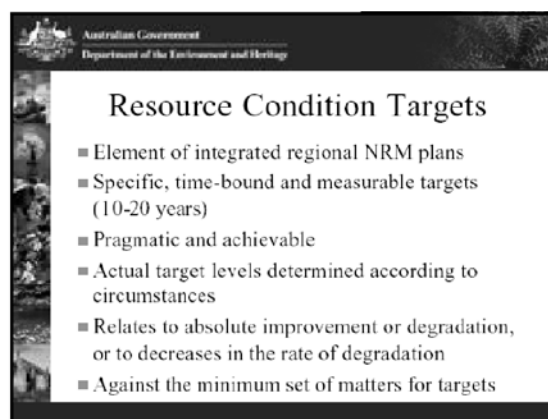
- Is to be useful to all NRM programme partners
- Simple, cost-effective, affordable, and practical
  - Avoids duplication of effort
  - Uses data for multiple purposes over a range of scales and levels (local, regional, state, national, international)
  - Ensures users can find and obtain suitable data
- Recognizes that NRM interventions encompass a range of time-scales
- Meaningful interpretation of data over time



Australian Government  
Department of the Environment and Heritage

### National S&T Framework

- Approved by NRM Ministerial Council 03 May 2002
- Revised to suit NHT
- Sets consistent national directions and approaches at all levels for :
  - Natural resource planning
  - Target setting
  - Action and performance measurement



Australian Government  
Department of the Environment and Heritage

### Resource Condition Targets

- Element of integrated regional NRM plans
- Specific, time-bound and measurable targets (10-20 years)
- Pragmatic and achievable
- Actual target levels determined according to circumstances
- Relates to absolute improvement or degradation, or to decreases in the rate of degradation
- Against the minimum set of matters for targets

# Attachment A

## Wetland Indicators Workshop Report

Australian Government  
Department of the Environment and Heritage

### Indicators and Protocols

- Indicators related to the matters for targets are being developed to:
  - Promote consistency in measuring progress towards targets within and across regions
  - Allow aggregation and reporting on progress over time
  - Allow comparison of NRM program outputs with national assessments of condition or trends in resource condition
  - Enable feedback to regions on how they are contributing to achievement of nationally agreed outcomes

Australian Government  
Department of the Environment and Heritage

### Wetland Condition Indicators: Selection Criteria

- Cost-effective, consistent, and practical.
- 'SMART': simple, measurable, accurate, relevant, and timely.
- Highly specialised freshwater ecology or geomorphology skills would preferably not be required.
- Include meaningful field measurements.
- Measurements accurately represents condition
- Referential
- Capable of providing an assessment of trends over time.
- No redundant or irrelevant components.
- The method can be implemented in a timely manner.
- Applicable to most / all Australian wetland types.

Australian Government  
Department of the Environment and Heritage

### Wetland Condition Indicators: Selection Criteria

- Rapid, cost-effective, provide timely results.
- Adequately "ground truthed".
- Capable of providing consistent and comparable assessments at broad spatial scales (within and between wetlands; for river basins, NAP and NHT II regions, at drainage divisions, State or Territory, and national scales).
- Based on existing monitoring techniques (rather than requiring extensive research prior to implementation).
- Have good technical support systems (such as software, documentation, QA/QC, and training and accreditation).

Australian Government  
Department of the Environment and Heritage

### Wetland Condition Indicators: Selection Criteria

Wetland Condition indicators should be based on monitoring

- A combination of abiotic and biotic components:
  - abiotic attributes of wetland extent, distribution, and condition (including geomorphology, hydrology and flow regime changes, fluvial processes, and / or physical and chemical condition);
  - biotic attributes (colonial nesting water birds, migratory shorebirds, riparian vegetation, macroinvertebrates, fish, and / or diatoms);
- Include the ecological processes which link the living and non-living components of river ecosystems (such as carbon and oxygen fluxes, benthic community respiration / metabolism, or chemical (N, P) and energy webs within the wetland ecosystem);
- Also, if possible, cover ecosystem services / benefits.

Australian Government  
Department of the Environment and Heritage

### Wetland Condition Indicators: Selection Criteria

- report on trends over time in wetlands of management concern;
- assess of wetland condition within and between NAP and NHT II regions;
- detect a 10% change in biological condition with 60% - 80% confidence, or with known variances;
- separate temporal variation from anthropogenic trends;
- be based on best available science;
- consistent with the Ramsar Convention, national NRM M&E, and the National Water Quality Management Strategy;
- Results must be capable of being mapped or displayed in an easy to interpret manner.

## Presentation C6: Wetland systems and types/ bioregionalisation

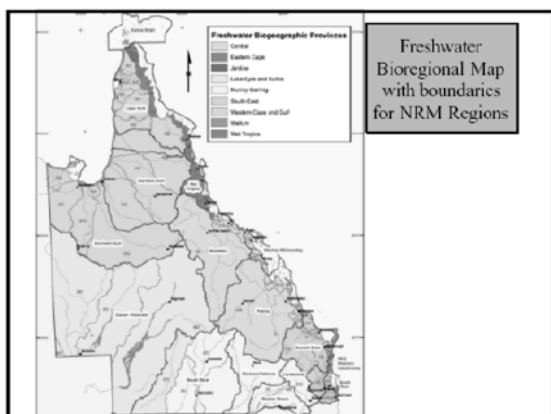
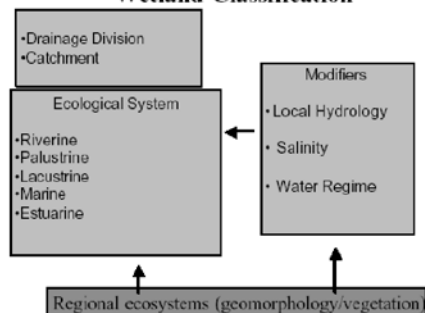
Bruce Wilson, Environmental Protection Agency, Queensland

### Wetland Definition

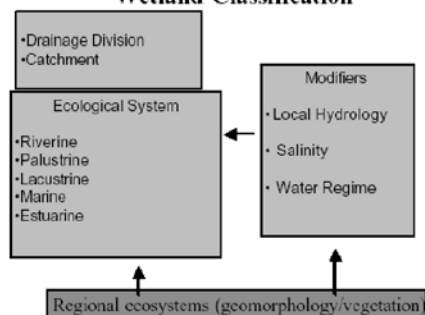
Areas of permanent or periodic/intermittent inundation, with water that is static or flowing fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed 6m. To be a wetland the area must have one or more of the following attributes:

- at least periodically the land supports plants or animals that are adapted to and dependent on living in wet conditions for at least part of their life cycle, or
- the substratum is predominantly undrained soils that are saturated, flooded or ponded long enough to develop anaerobic conditions in the upper layers, or
- the substratum is not soil and is saturated with water, or covered by water at some time,

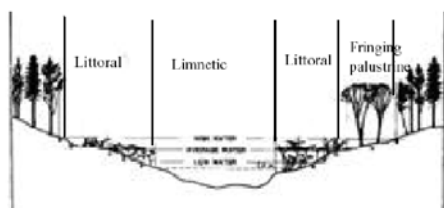
### Wetland Classification



### Wetland Classification



### Lacustrine

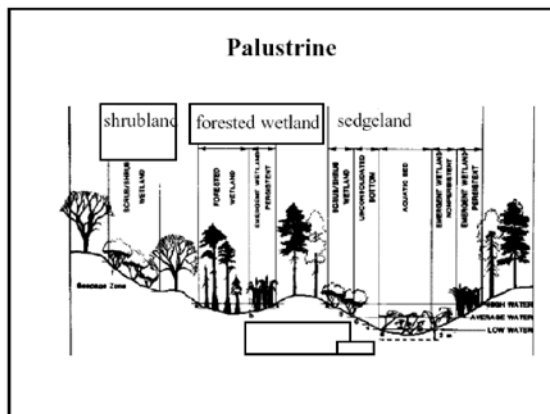


### Lacustrine

- Inland versus coastal
- Permanent to ephemeral hydrology
- Fresh to Saline chemistry
- Geomorphic setting ranges from perched versus overflow versus dune field lakes
- Disturbances to hydrology, grazing of fringes..

# Attachment A

## Wetland Indicators Workshop Report

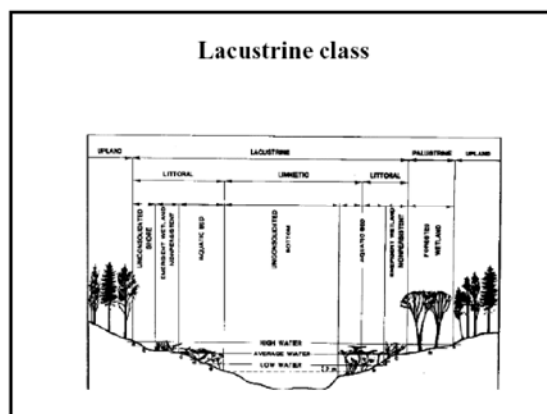


**Palustrine**

- Geomorphic setting - depressions on floodplains, closed depressions on Tertiary plateaus, billabongs, seeps on sides of hills..
- Vegetation ranges from (paperbark) woodlands to sedgelands and aquatics
- Disturbance includes bunding, grazing, weeds, cropping, draining, lazer leveling, catchment disruption to hydrology etc

**Ground Water**

**Springs, peat, fens, karsts**



## Presentation C7: Pressures and Threats

John Bennett, Environmental Protection Agency, Queensland

**Wetland Threats**

based on  
**Coastal CRC Wetlands Research for Management**

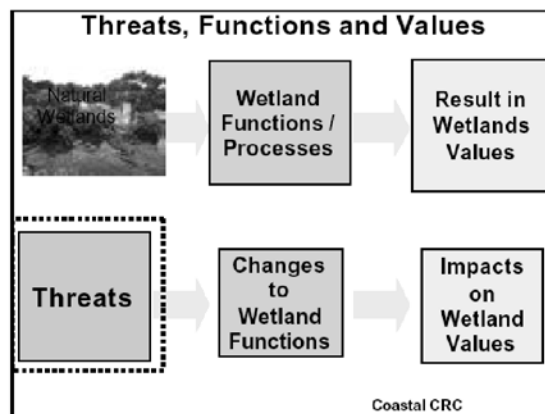


**EPA Wetlands Conservation and Management Implementation Plan**  
FEBRUARY 12, 2004

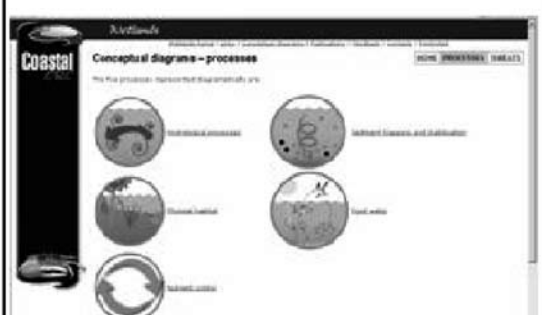
**PURPOSE OF THIS IMPLEMENTATION PLAN**

1. To integrate various wetlands related programs and projects into a single strategic framework which will guide the Agency's coordinated and integrated approach to wetlands conservation and management, including restoration and achieve the Agency's target for wetlands protection.
2. To set the requirement of the "Strategy for the Conservation and Management of Queensland Wetlands, 1999 (revised Strategy)" which requires the EPA to develop a coordinated Implementation Plan.

Coastal CRC



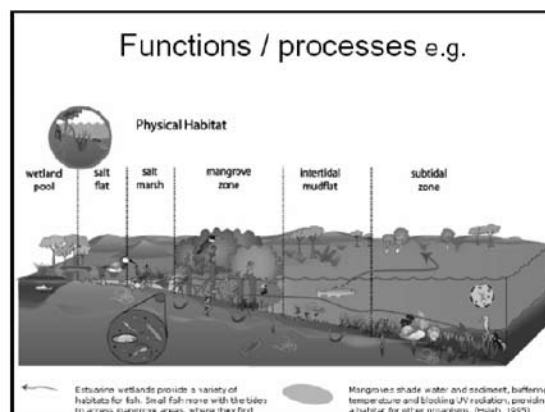
**Functions/processes** are what wetlands do  
([www.coastal.crc.org.au/wetlands](http://www.coastal.crc.org.au/wetlands))



**Conceptual diagrams - processes**

These five processes represent the major functions of wetlands:

- Hydrological processes
- Soil formation and stabilization
- Carbon sequestration
- Food web
- Wetland succession



**Values** are attributes with subjective worth, merit, quality, or importance e.g.

- direct uses - food, recreation, or timber
- indirect uses - water quality, flood control
- possible future uses - biodiversity or conserved habitats
- cultural and spiritual value
- existence value

Coastal CRC

**Threats** are actions that have the potential to impact negatively on wetland functions / processes and hence their associated values

Coastal CRC

# Attachment A

## Wetland Indicators Workshop Report

### Threats

- Draining, filling and bed mining (dredging) of wetlands
  - impacts on all wetland processes
- Hydrological modification
  - impact on surface and ground water hydrology and there is some uncertainty about its effects on other wetland processes and attributes
- Effect of increased hydraulic efficiency of river channels
  - impact on filter function of wetlands and surface and ground water hydrology
- Water pollution
  - impact on water quality, habitat provision and biogeochemical cycling and biological function

Coastal CRC

### Threats (continued)

- Nutrient enrichment
  - impact on water quality, primary productivity and biogeochemical cycling
- Erosion and sediment inputs
  - impact on water quality, biological functioning and biogeochemical cycling
- Invasion by pest species
  - threaten habitat provision, biodiversity and biological function
- Stock access
  - threaten water quality, habitat provision and biodiversity

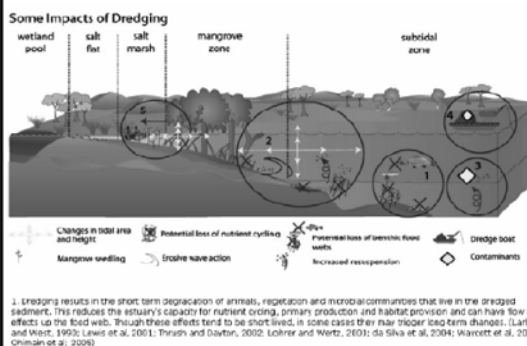
Coastal CRC

### Threats (continued)

- Salinisation
  - threaten water quality, biogeochemical cycling, habitat provision and biological function
- Climate change
  - threat but limited understanding about the actual impacts
- Recreational activities - less threatening to wetlands
- Removal of riparian vegetation
  - impact on wetlands, habitat provision and biodiversity and maybe filter function and biogeochemical cycling
- Barriers - impacts on a range of wetland functions

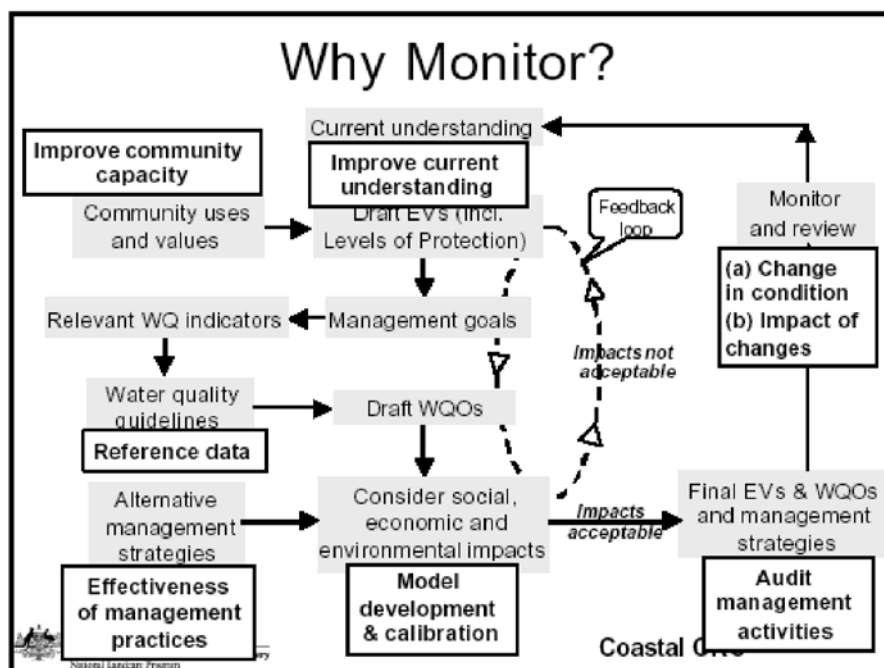
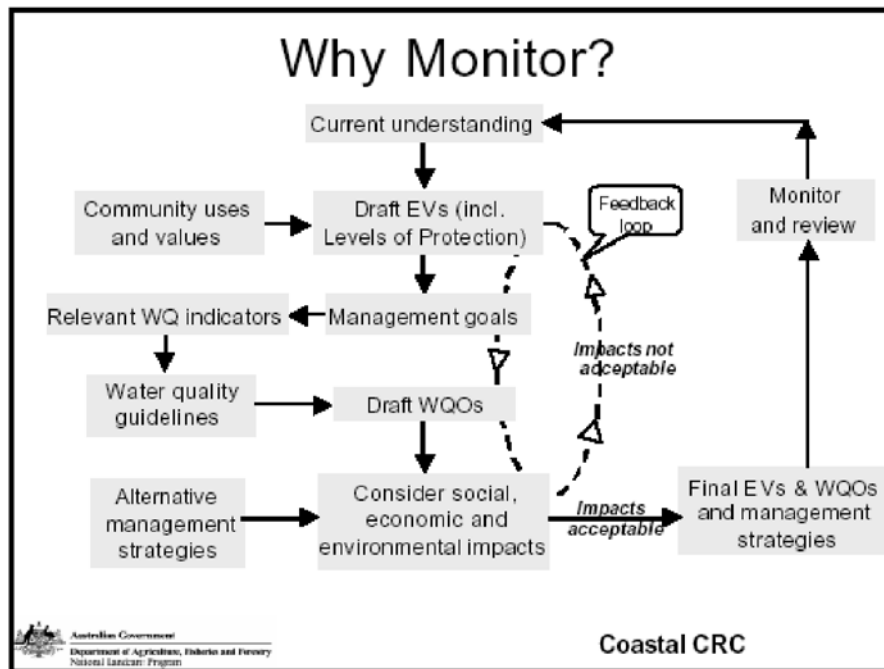
Coastal CRC

### Impacts of threats on processes e.g.



## Presentation C8: Why Monitor

John Bennett, Environmental Protection Agency, Queensland



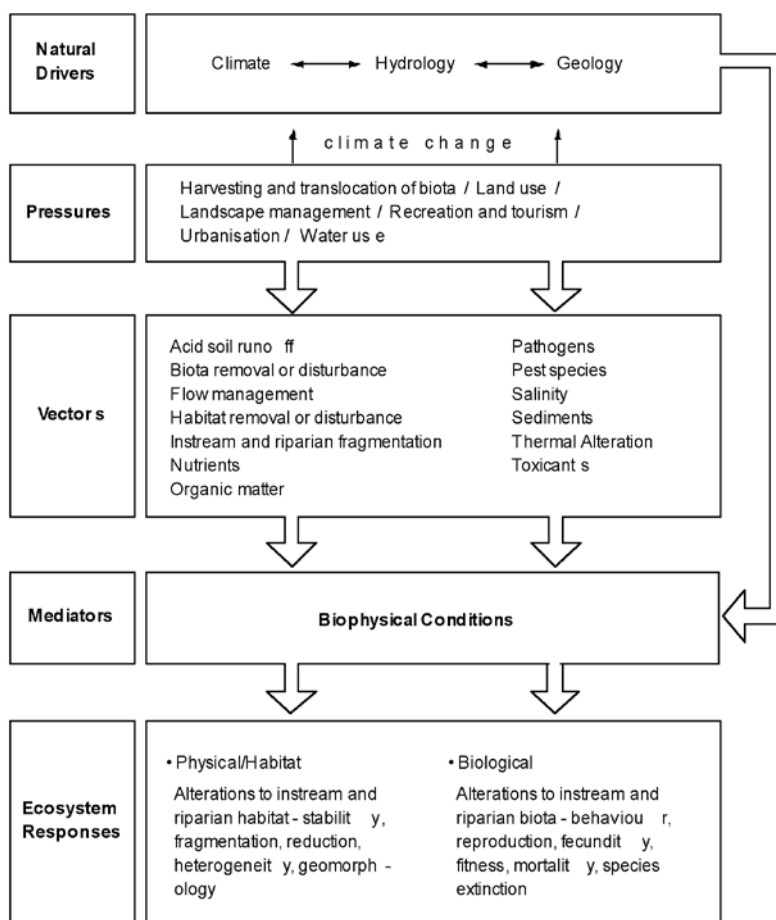
# Attachment A

## Wetland Indicators Workshop Report

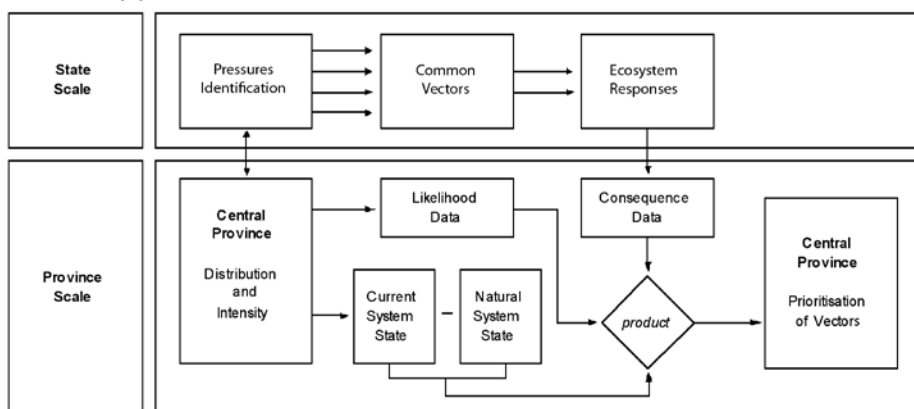
### Presentation C9: Stream and Estuaries Assessment Program

Glen Moller, Department of Natural Resources & Water, Queensland

#### Pressure - Vector - Response (PVR) Framework

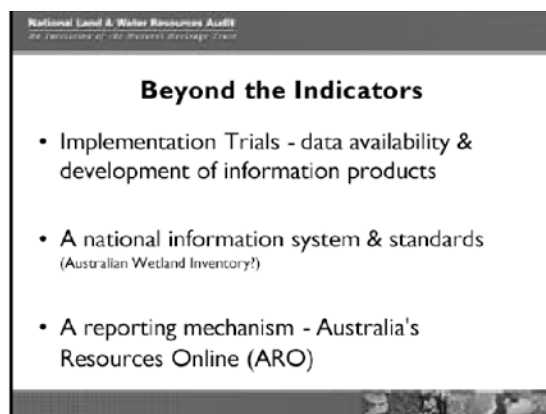
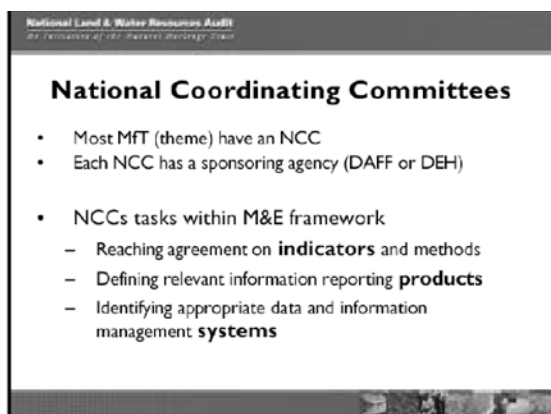
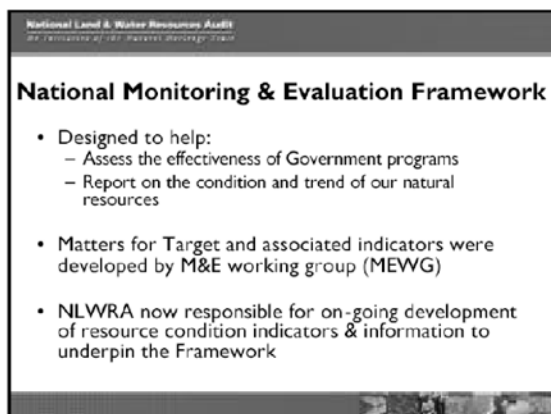
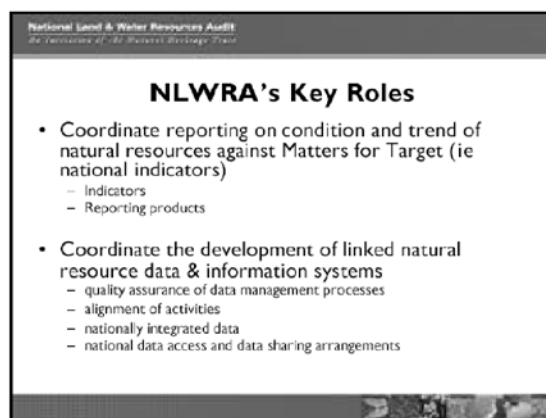
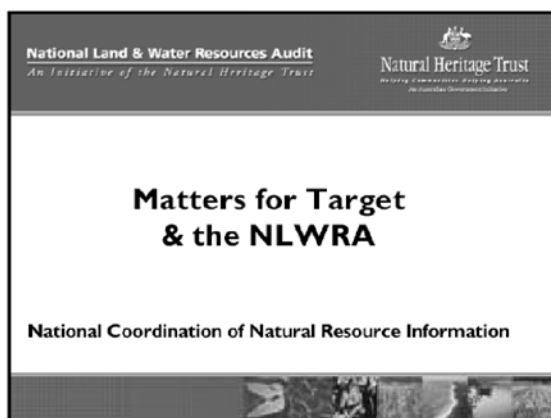


#### PRV models for Queensland aquatic ecosystems applied to Central Province



## Presentation C10: Matters for Target and the NLWRA

Alana Innes, National Land & Water Resources Audit, Australian Government



# Attachment A

## Wetland Indicators Workshop Report

### Appendix D: Workshop Groups

| Lacustrine groups                                                                                                                                                |                                                                                                                                                                                          |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Arid zone lakes (salt)</b><br>Louisa Davis<br>Roger Jaensch<br>Glenn McGregor<br>Glen Scholz<br>Simon Ward<br>Bruce Wilson                                    | <b>Inland non-arid (depressional)</b><br>Donna Audas<br>Stewart Blackhall<br>Cassie Burns<br>Barry Butler<br>Lynda Collins<br>Alison Curtin<br>Danielle Hardie<br>John Lowry<br>Jim Tait |
| <b>Artificial</b><br>Mark Cushing<br>Steve Elson<br>Alana Innes<br>Belinda McGrath-Steer<br>Glen Moller<br>Naomi Nelson<br>Clayton Vale<br>Christian Witte       | <b>Inland salt</b><br>Paul Frazier<br>Bruce Gray<br>Mike Lyons<br>Peter Macdonald<br>Kay Montgomery<br>Peter Negus<br>Lynne Turner                                                       |
| <b>Coastal dune</b><br>Jenny Davis<br>Peter Gehrke<br>Jon Marshall<br>Phil Papas<br>David Reid<br>Mike Ronan<br>Holly Smith<br>Brian Stockwell<br>Terri Svensson | <b>Terminal depression</b><br>John Bennett<br>Andrew Brooks<br>Paul Clayton<br>Brendan Edgar<br>Jonathon Hodge<br>Arthur Knight<br>John Patten<br>Sarah Young                            |

# Appendices

| Palustrine groups                                                                                                                                   |                                                                                                                                                                |
|-----------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Artificial (bore drains)</b><br>Kay Montgomery<br>John Bennett<br>Brendan Edgar<br>Jonathon Hodge<br>Arthur Knight<br>John Patten<br>Sarah Young | <b>Freshwater meadows</b><br>Mark Cushing<br>Alana Innes<br>Glen Moller<br>Naomi Nelson<br>Clayton Vale<br>Christian Witte<br>Danielle Hardie<br>Satish Choy   |
| <b>Coastal forest</b><br>Brian Stockwell<br>Stewart Blackhall<br>Cassie Burns<br>Barry Butler<br>Lynda Collins<br>Alison Curtin                     | <b>Inland arid zone swamps</b><br>Louisa Davis<br>Janet Holmes<br>Roger Jaensch<br>Glenn McGregor<br>Simon Ward                                                |
| <b>Coastal sedge</b><br>Donna Audas<br>John Lowry<br>Jim Tait<br>Paul Frazier<br>Bruce Gray<br>Peter Macdonald<br>Peter Negus<br>Lynne Turner       | <b>Herbs and forbs</b><br>Jenny Davis<br>Peter Gehrke<br>Jon Marshall<br>Phil Papas<br>David Reid<br>Mike Ronan<br>Holly Smith<br>Terri Svensson<br>Mike Lyons |
| <b>Natural groundwater</b><br>Glen Scholz<br>Bruce Wilson<br>Steve Elson<br>Belinda McGrath-Steer<br>Paul Clayton<br>Rod Fensham<br>Brad Lewis      |                                                                                                                                                                |

# Attachment A

## Wetland Indicators Workshop Report

### Appendix E: Palustrine/Lacustrine Definitions

#### Lacustrine System

From Cowardin et al. 1979.

"The Lacustrine System (Figure 1) includes wetlands and deepwater habitats with all of the following characteristics: (1) situated in a topographic depression or a dammed river channel; (2) lacking trees, shrubs, persistent emergents, emergent mosses or lichens with greater than 30 percent areal coverage; and (3) total area exceeds 8ha (20 acres). Similar wetland and deepwater habitats totalling less than 8ha are also included in the Lacustrine System if an active wave-formed or bedrock shoreline feature makes up all or part of the boundary, or if the water depth in the deepest part of the basin exceeds 2m (6.6 feet) at low water."

For the WMC project, lacustrine water may be tidal or non-tidal but ocean derived salinity is always less than 0.5ppt (Cowardin et al. 1979).

"Limits. The Lacustrine System is bounded by upland or by wetland dominated by trees, shrubs, persistent emergents, emergent mosses, or lichens. Lacustrine Systems formed by damming a river channel are bounded by a contour approximating the normal spillway elevation or normal pool elevation, except where Palustrine wetlands extend lakeward of that boundary. Where a river enters a lake, the extension of the Lacustrine shoreline forms the Riverine-Lacustrine boundary.

**Description.** The Lacustrine System includes permanently flooded lakes and reservoirs (e.g., Lake Superior), intermittent lakes (e.g., playa lakes), and tidal lakes with ocean-derived salinities below 0.5 percent (e.g., Grand Lake, Louisiana). Typically, there are extensive areas of deep water and there is considerable wave action. Islands of Palustrine wetland may lie within the boundaries of the Lacustrine System."

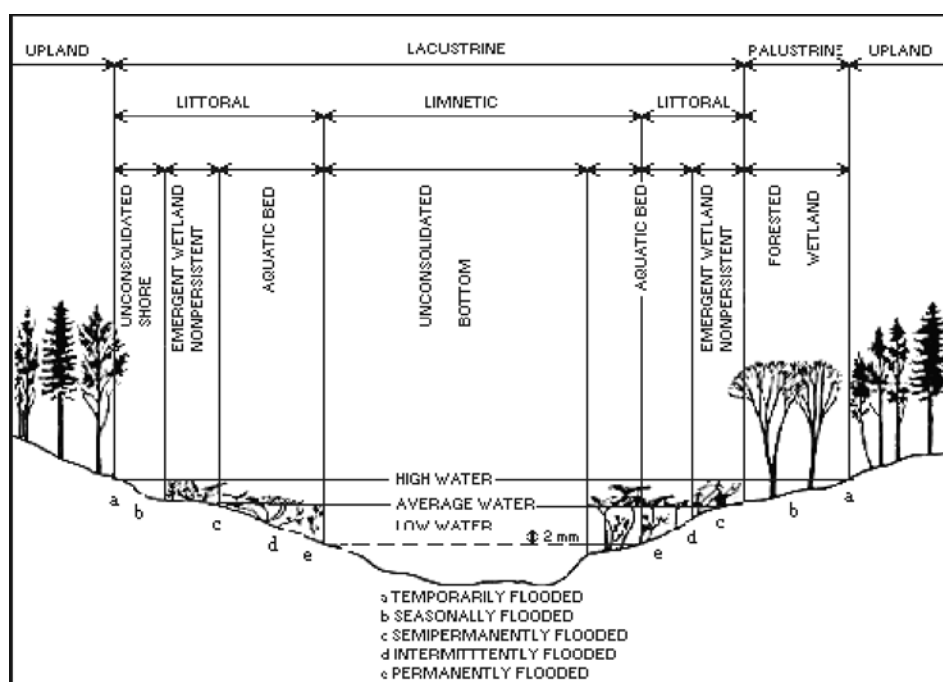


Figure 1. Distinguishing features and examples of habitats in the lacustrine system (from Cowardin et al. 1979).

## Palustrine System

The following is taken from Cowardin et al. (1979) and Blackman et al. (1992) and slightly modified to fit the Australian environment.

The palustrine system includes all non-tidal wetlands dominated by trees, shrubs, persistent emergents, emergent mosses or lichens, and all such wetlands that occur in tidal areas where salinity due to ocean-derived salts is below 0.5 percent. It also includes wetlands lacking such vegetation which have the following three characteristics: (a) where active waves are formed or bedrock features are lacking; (b) where the water depth in the deepest part of basin less than 2m at low water; and (c) the salinity due to ocean-derived salts is still less than 0.5 percent.

**Boundaries.** The palustrine system is bounded by upland or by any of the other four systems.

**Description.** The palustrine system was developed to group the vegetated wetlands traditionally called by such names as marsh, swamp, bog, fen, and prairie, which are found throughout the world. It also includes the small, shallow, permanent or intermittent water bodies often called ponds. Palustrine wetlands may be situated shoreward of lakes, river channels, or estuaries; on river floodplains; in isolated catchments; or on slopes. They may also occur as islands in lakes or rivers. The erosive forces of wind and water are of minor importance except during severe floods.

The emergent vegetation adjacent to rivers and lakes is often referred to as “the shore zone” or the “zone of emergent vegetation” (Reid and Wood 1976), and is generally considered separately from the river or lake. As an example, Hynes (1970:85) wrote in reference to riverine habitats: “We will not here consider the long list of emergent plants which may occur along the banks out of the current, as they do not belong, strictly speaking, to the running water habitat”. There are often great similarities between wetlands lying adjacent to lakes or rivers and isolated wetlands of the same class in basins without open water.

**Figure 2. Distinguishing features and examples of habitats in the palustrine system (from Cowardin et al. 1979).**

# Attachment A Wetland Indicators Workshop Report

## Appendix F: Lacustrine Conceptual Models



## Terminal depression lakes Lacustrine



- ① Terminal depression lakes are shallow, highly turbid 🌫️ and largely heterotrophic in the main water body and autotrophic at the margins
- ② Sediment layers can be up to 3m deep 📏, laid down over 100,000 years
- ③ Lignum plants 🌿 can cover much of the lake
- ④ Fish 🐟 and bird 🐦 abundance is high
- ⑤ Boom bust populations of invertebrates 🐛
- ⑥ River inflow brings nutrients 🌊, sediments 🌫️, organic carbon 🌿 and organisms 🐛
- ⑦ There are high transpiration 🌿 and evaporation 🌬️ rates

### Dry Phase

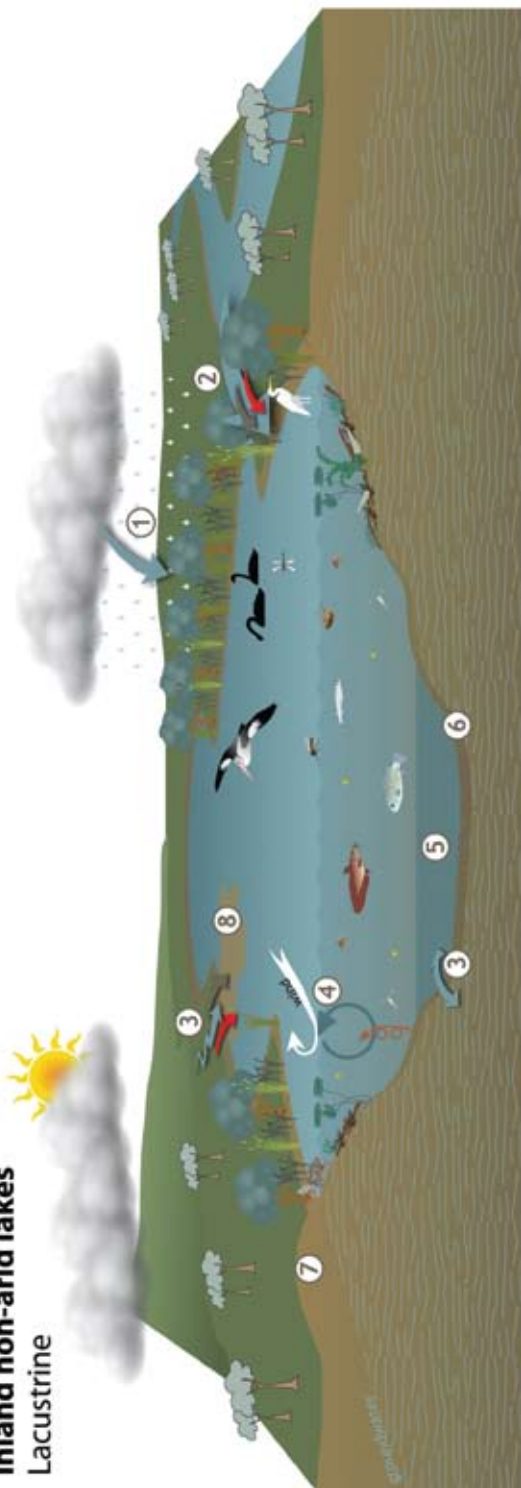
- Low fish and bird abundance



### Threats to terminal depression lakes

# Attachment A Wetland Indicators Workshop Report

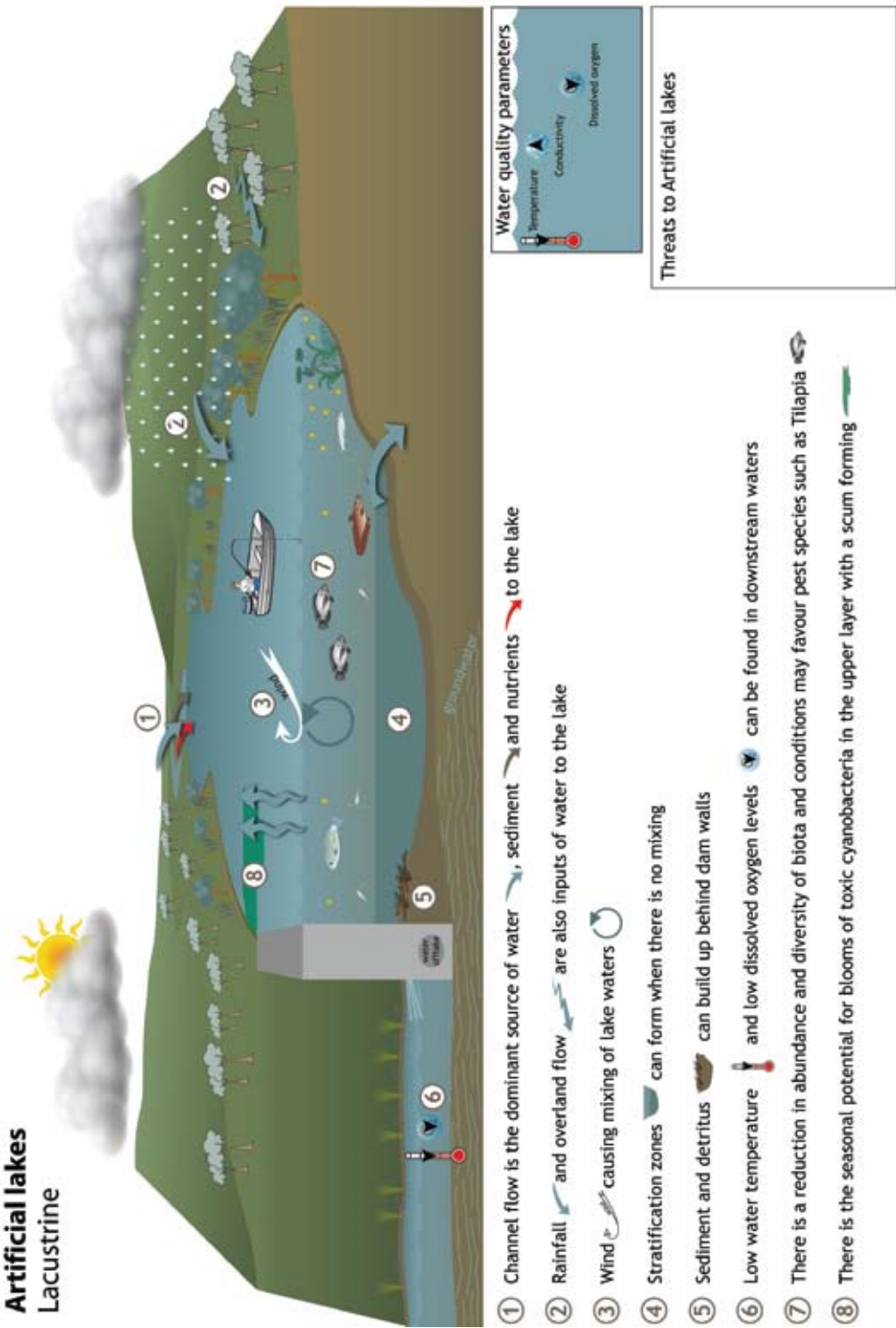
## Inland non-arid lakes Lacustrine



- ① Precipitation is the major input to the lake
  - ② Overbank flow from adjacent rivers can provide the largest single input to the lake in flood events
  - ③ Overland flow and groundwater are also minor inputs to the lake
  - ④ Winds can cause resuspension of sediments, and also mixes water
  - ⑤ Stratification zones can form when there is no mixing
  - ⑥ Fine sediments build up on the bottom of the lake
  - ⑦ Levee banks
  - ⑧ Turbidity is variable with sediment entering the lake in overland and overbank flow
- Dry Phase**
- Dissolved oxygen drops

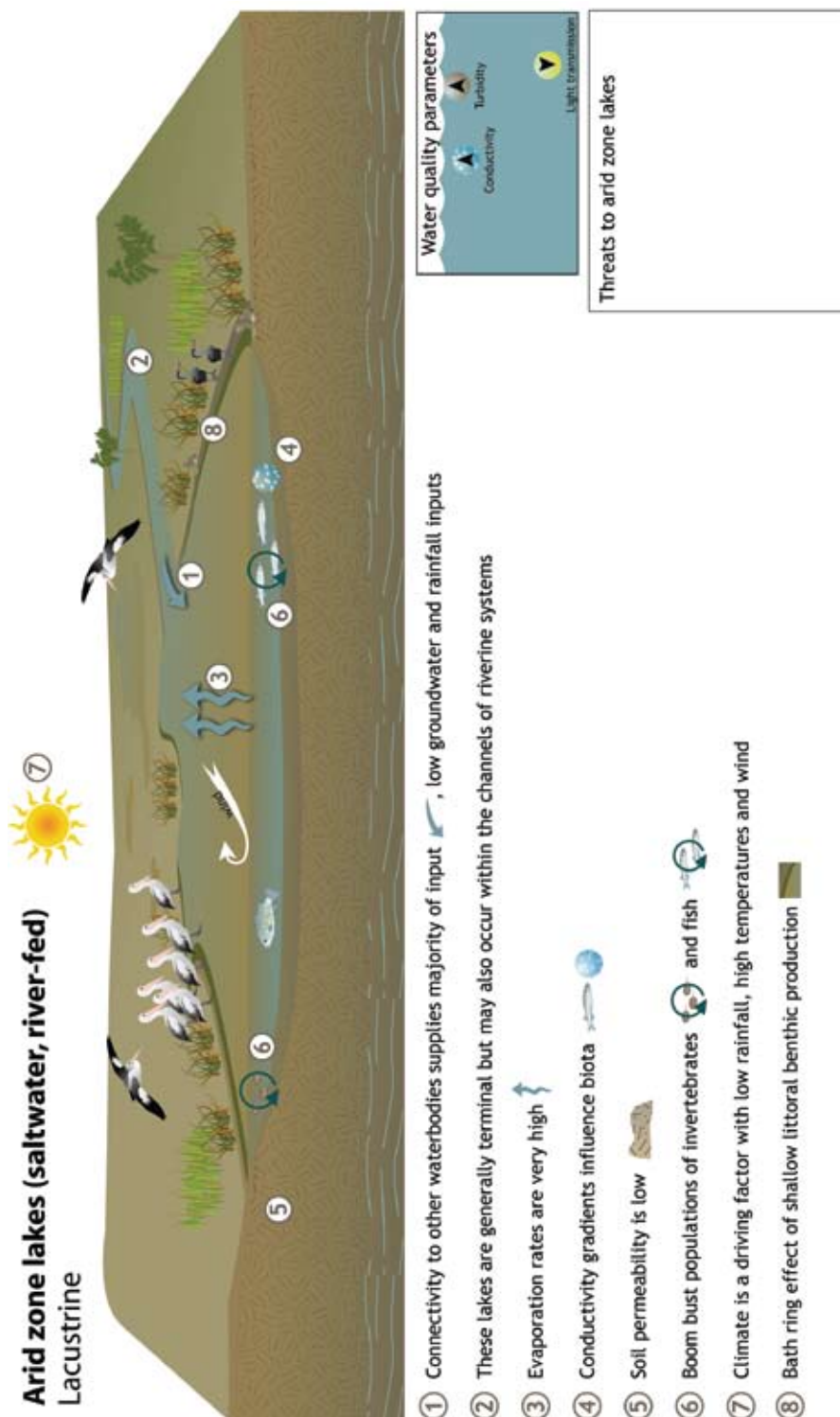


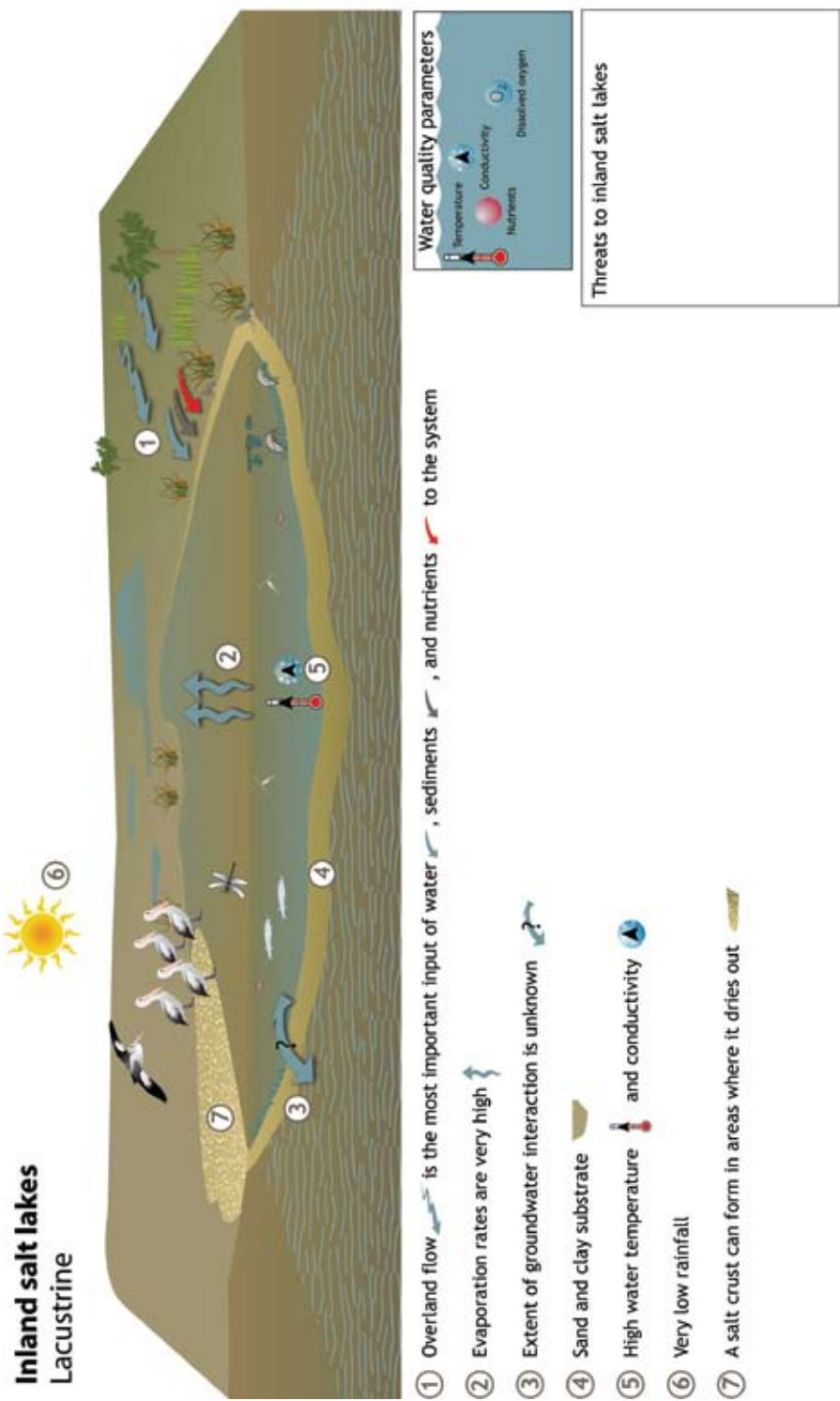
Threats to inland non arid lakes



# Attachment A

## Wetland Indicators Workshop Report

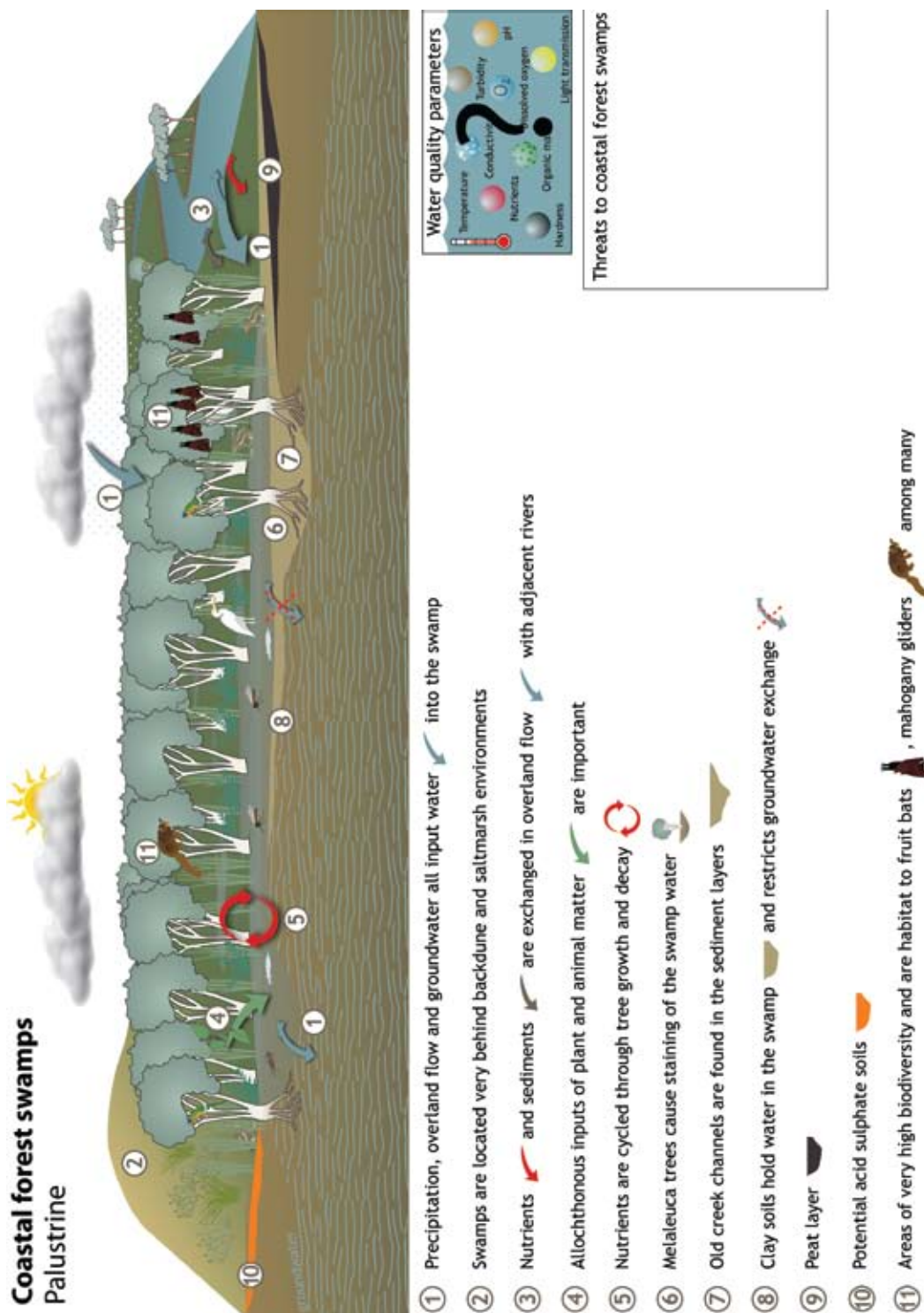




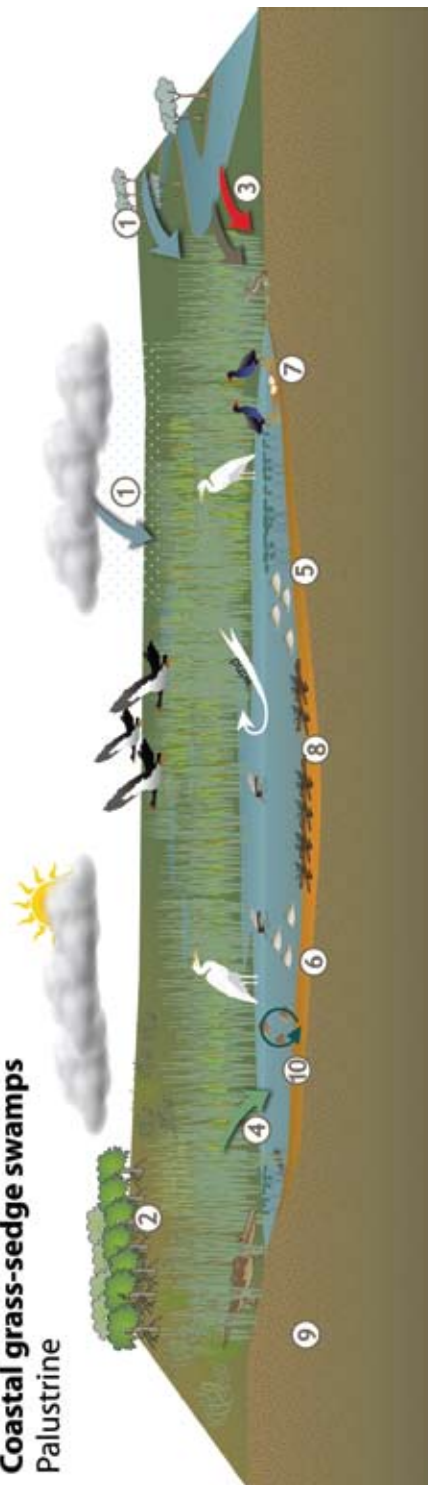
# Attachment A

## Wetland Indicators Workshop Report

### Appendix F: Palustrine Conceptual Models



## Coastal grass-sedge swamps Palustrine



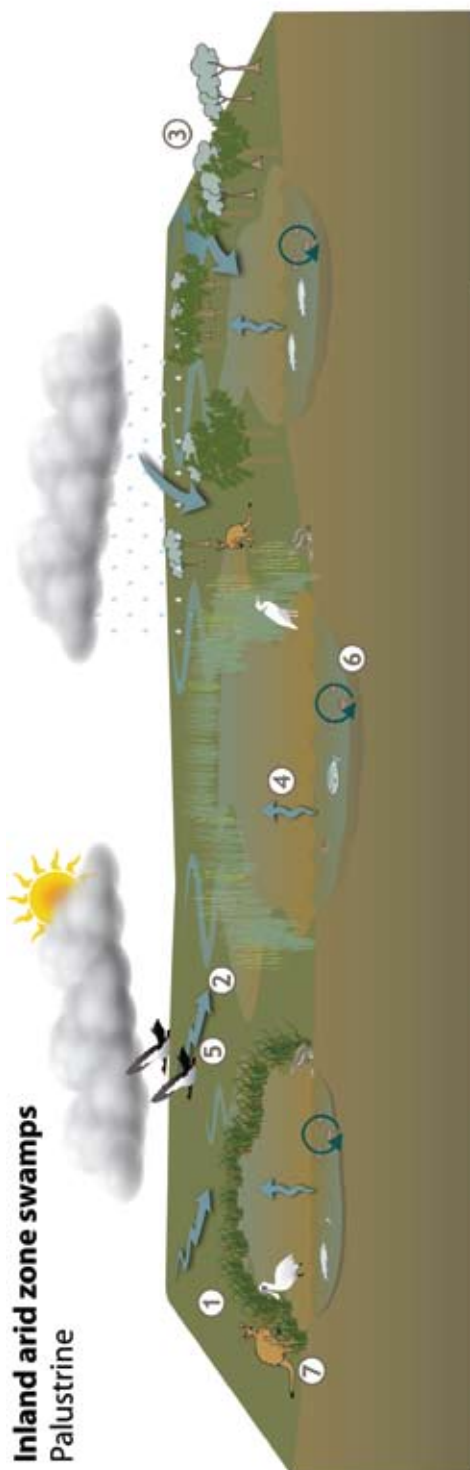
- ① Overbank flow and precipitation are the major inputs of water into the swamp
- ② Swamps are located very close to marine environments
- ③ Nutrients and sediments are important inputs to the swamp
- ④ Allochthonous inputs of plant and animal matter dominate
- ⑤ Coastal swamps are an important fish nursery for fish species such as barramundi
- ⑥ Fish abundance is high in swamps but species diversity is low
- ⑦ Swamps are an important breeding area for waterfowl
- ⑧ Potential acid sulphate soils
- ⑨ Fine sediments due to it being an old marine plain
- ⑩ Boom and bust invertebrates



Threats to coastal sedge swamps

# Attachment A Wetland Indicators Workshop Report

## Inland arid zone swamps Palustrine



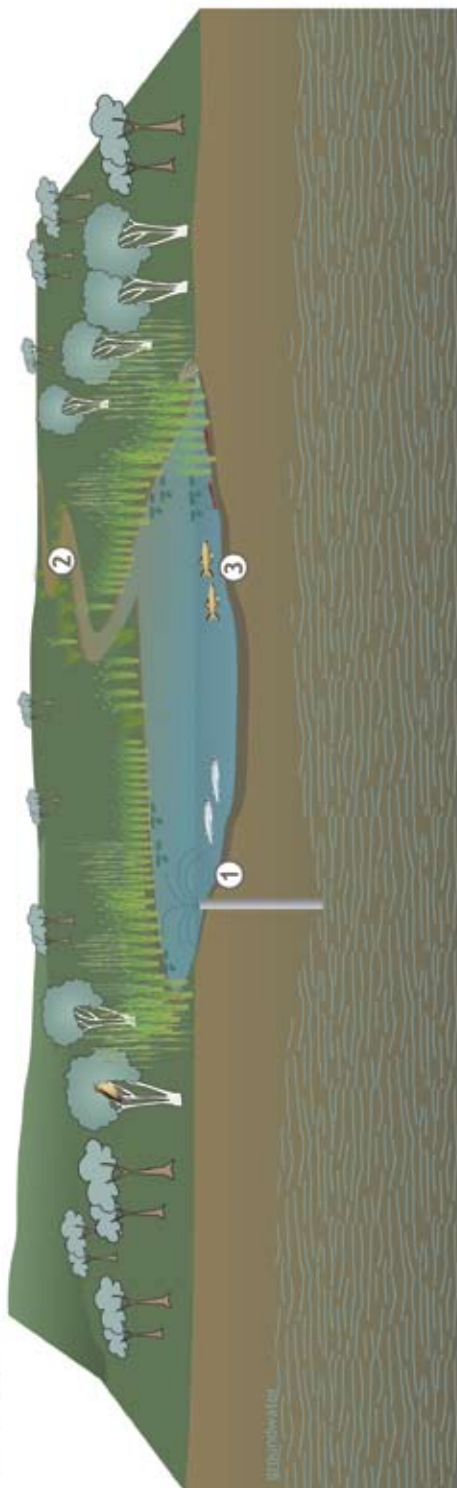
Arid zone swamps are defined by their vegetation:

- ① Shrub swamps: dominated by lignum , inputs from precipitation , overland and overbank flow
- ② Grass swamps: dominated by grasses , inputs from precipitation and overland flow
- ③ Wooded swamps: dominated by trees , inputs from precipitation , overland and overbank flow
- ④ Evaporation rates are high
- ⑤ Arid zone swamps (especially shrub swamps) are important habitats for birds
- ⑥ Boom bust populations of invertebrates
- ⑦ Swamps are an important habitat for terrestrial grazers

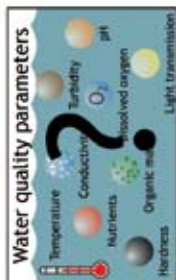


Threats to arid zone swamps

## Artificial bore drains Palustrine



- ① Groundwater fed systems from the Great Artesian Basin
- ② Water quality decreases and weeds increase with distance down channel
- ③ These bore drains may be the only available habitat for some biota in areas where natural artesian springs have dried

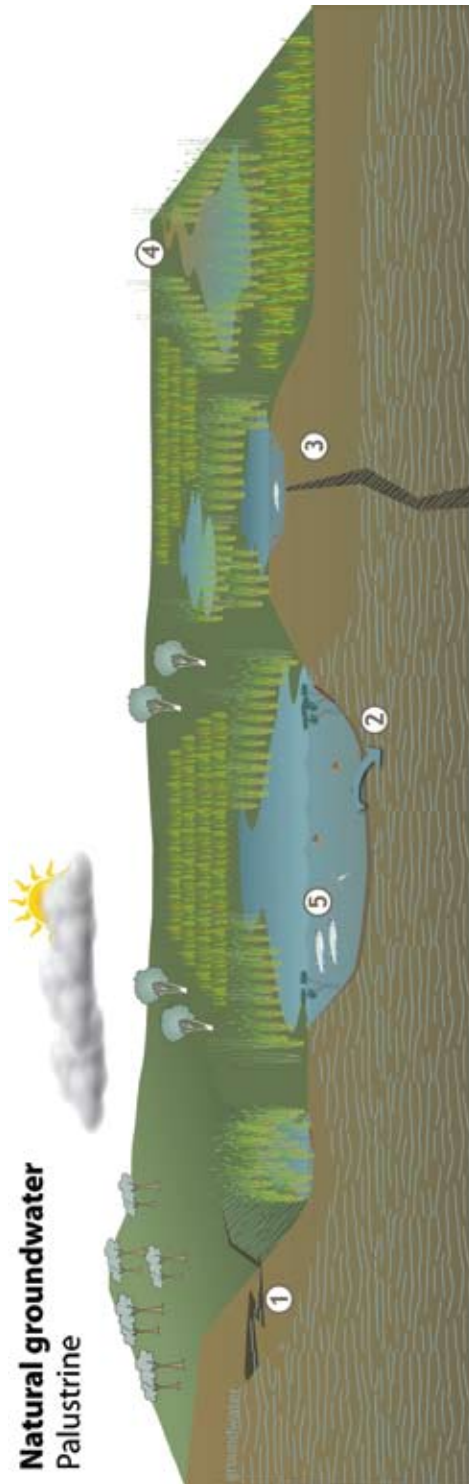


Threats to artificial bore drains

# Attachment A

## Wetland Indicators Workshop Report

### Natural groundwater Palustrine



- ① Break of slope, fractured rock groundwater spring with a local water source
- ② Watertable induced groundwater spring sourced by regional water source
- ③ Mound spring fed by artesian water
- ④ Can form into a channel with enough water flow
- ⑤ High level of endemic species



Threats to natural groundwater  
springs

